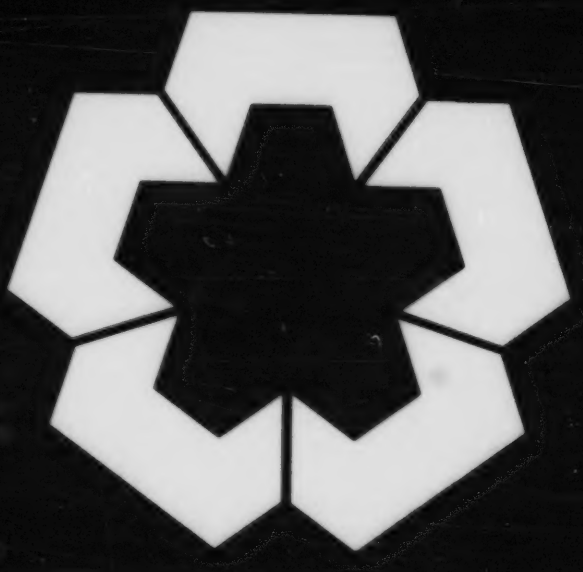

Urban Air Quality Research Needs In Alberta: A Literature Review And Synthesis Of Available Information

RMD Report 85 33

Alberta

86-03220/

The logo represents the interdisciplinary and holistic nature of the Division's environmental research programs. Each of the five sections of the symbol represent comprehensive programs on air, water, land, humans, and their constant interaction. The sections converge to form a cohesive chain, characteristic of an effective research organization. This cohesive bonding makes the sections blossom into the environment in the form of a flower — an Albertan wild rose.

URBAN AIR QUALITY RESEARCH NEEDS IN ALBERTA: A LITERATURE REVIEW AND SYNTHESIS OF AVAILABLE INFORMATION

RESEARCH MANAGEMENT DIVISION
Alberta Environment

Further information about reports published by the Research Management Division is available from:

Research Management Division
Publications Office
14th Floor, Standard Life Centre
10405 Jasper Avenue
Edmonton, Alberta
T5J 3N4

(403) 427-3946

This report may be cited as:

Jandali, T. and B. Hrebenyk. 1985. Urban air quality research needs in Alberta: A literature review and synthesis of available information. Prep. for Alberta Environment, Research Management Division by ESL Environmental Sciences Limited. Edmonton, Alberta: Research Management Division. RMD Report 85/33. 188 pp.

DISCLAIMER

Research Management Division has attempted to provide ESL Environmental Sciences Limited with all literature directly related to urban air quality research within Alberta. This was accomplished by searching all major government and academic library holdings in the province. In addition, direct contact with government, academic, and private atmospheric researchers involved in urban air quality projects was made, and ESL Environmental Sciences Limited was directed to solicit relevant material from scientists and organizations through both telephone and personal interviews.

Literature describing current national and international urban air quality research was chosen through an extensive search of major computerized literature data bases. Subsequent screening by a selection committee then took place to choose a cross-section of the most current, peer reviewed and relevant material available. No attempt was made to identify all literature. Only that which would allow the Alberta research to be placed in context of relevance and acceptability was chosen for review. Consequently, it is possible that pertinent reports/papers may have been excluded inadvertently, thereby presenting an incomplete picture of some research areas.

This report is made available as a public service. The Alberta Department of Environment neither approves nor disagrees with the conclusions expressed herein, which are the responsibility of the authors.

URBAN AIR QUALITY RESEARCH NEEDS IN ALBERTA: A LITERATURE REVIEW AND SYNTHESIS OF AVAILABLE INFORMATION

by

T. JANDALI and B. HREBENYK
ESL Environmental Sciences Limited

for

RESEARCH MANAGEMENT DIVISION
Alberta Environment

1985

TABLE OF CONTENTS

		Page
LIST OF TABLES		ix
ABSTRACT		xi
1.	INTRODUCTION	1
2.	STUDY SCOPE AND OBJECTIVES	3
3.	REVIEW OF ALBERTA URBAN AIR QUALITY LITERATURE	5
3.1	Inventories of Pollutant Emissions in Alberta	5
3.2	Air Quality Monitoring Data Base	8
3.2.1	National/Provincial Air Quality Standards	8
3.2.2	Air Quality Monitoring in Alberta	8
3.2.3	Pollutant Concentrations Recorded in Edmonton and Calgary	11
3.2.3.1	Oxides of Nitrogen	13
3.2.3.2	Ozone	15
3.2.3.3	Carbon Monoxide (CO)	17
3.2.3.4	Sulphur Compounds	19
3.2.3.5	Hydrocarbons	21
3.2.3.6	Particulates	24
3.3	Meteorological Monitoring	28
3.3.1	Temperature and the Urban Heat Island	28
3.3.2	Surface Winds and Turbulence	32
3.3.3	Mixing Heights	33
3.3.4	Ventilation	35
3.3.5	Frequency and Influence of Chinooks	36
3.4	Air Quality Modelling in Alberta	40
3.4.1	Dispersion Modelling	41
3.4.2	Chemical Transformation Modelling	43
3.5	Studies of Effects/Consequences of Air Pollution in Alberta	45
3.5.1	Health Effects	45
3.5.2	Nuisance Effects	47
3.5.3	Inadvertent Climate Modification	48
3.5.4	Public Concern and the Index of Quality of of Air System	48
4.	NATIONAL/INTERNATIONAL LITERATURE REVIEW	51
4.1	Atmospheric Processes in Urban Air Quality	51
4.1.1	Meteorological Factors Affecting Air Pollution	51
4.1.2	Pollutant Transformation in the Atmosphere	59
4.1.2.1	Gaseous Transformations	60
4.1.2.2	Liquid Phase Transformation	65
4.1.3	Removal Processes	67
4.2	Urban Air Quality Monitoring	69
4.2.1	Definition of Monitoring Objectives	70

Continued . . .

TABLE OF CONTENTS (CONCLUDED)

		Page
4.2.2	Parameters to be Monitored	73
4.2.3	Criteria for Siting Monitoring Stations	75
4.2.4	Measurement Methods	82
4.3	Urban Air Quality Modelling	85
4.3.1	Modelling Techniques	87
4.3.1.1	Gaussian Plume Dispersion Models	89
4.3.1.2	Simple Box Models	91
4.3.1.3	Numerical Models	93
4.3.1.4	Receptor-Oriented Models	95
4.3.2	Limits of Model Accuracies	97
4.3.3	Future Modelling Requirements	104
4.4	Effects/Consequences of Air Pollution	105
4.4.1	Health Effects	106
4.4.2	Nuisance Effects	118
4.4.3	Effects on Climate	119
4.4.4	Actual versus Perceived Effects	121
5.	INTERVIEWS WITH ALBERTA'S RESEARCH COMMUNITY	124
6.	SUMMARY AND CONCLUSIONS	127
7.	RECOMMENDATIONS FOR URBAN AIR QUALITY RESEARCH IN ALBERTA	131
7.1	Long-Term Research Needs	132
7.2	Short-Term Research Needs	134
7.3	Recommendations for Research in Response to Perceived Public Concerns	140
7.3.1	Ambient Air Quality Objectives	140
7.3.1.1	Background	140
7.3.2	Air Quality Index	142
7.3.2.1	Background	142
7.3.3	Indoor Air Quality	143
7.3.3.1	Background	143
8.	REFERENCES CITED	144
9.	OTHER REFERENCES OF INTEREST TO URBAN AIR QUALITY RESEARCH	163
9.1	Alberta Publications Reviewed But Not Cited	163
9.2	National/International Literature Reviewed But Not Cited	164
9.3	Available on Microfiche	175
10.	APPENDIX	181
10.1	Summary of Research Recommendations made by Individuals Interviewed in Alberta	181
10.2	List of Acronyms and Symbols	187

LIST OF TABLES

		Page
1.	National Ambient Air Quality Objectives	9
2.	Provincial Ambient Air Quality Standards	10
3.	Relative Importance of Meteorological Factors to Pollution Processes	52
4.	Applications of Meteorological Mesoscale Models	57
5.	Threshold Energies for Photo Dissociation of Tropospheric Tropospheric Molecules of Importance for Ozone Budget in the Troposphere	61
6.	Recommended Criteria for Siting Monitoring Stations	74
7.	Monitoring Site Types for Photochemical Pollutants	76
8.	Regulatory Requirements for Minimum Number of Monitoring Sites	79
9.	Minimum Network for Monitoring around Designated Sources	80
10.	Summary of General Rules for Establishing NAPS Network Stations	81
11.	Air Quality Standard Reference Methods in Use in the USA	83
12.	The Underlying Predictor Models for Regional Air Quality Policy Analysis in Denver, Colorado	88
13.	Summary of Aerometric and Emissions Information Available for 1974 June 26-28 for the South Coast Air Basin	100
14.	Summary of Additional Meteorological Measurements Needed for Model Evaluation	102
15.	Summary of Additional Chemical Measurements Needed for Model Evaluation	103

Continued . . .

LIST OF TABLES (CONCLUDED)

		Page
16.	Types of Effects of Some Important Air Pollutants	107
17.	Summary of Reported Effects of Inhalation of Sulphur Dioxide	109
18.	Concentrations of H_2S and Human Health Effects	110
19.	Alberta Air Quality Standards	112
20.	Comparison of Federal, Provincial, and Recently Proposed Standards for Ambient NO_2 Concentrations....	114
21.	Summary of Reported Effects of Inhalation of Nitrogen Dioxide	115

ABSTRACT

The report identifies short- and long-term urban air quality research and monitoring needs for Alberta. The identification of these needs was achieved through (1) a review and synthesis of available information pertaining to air pollution in Alberta, (2) a summary of the current state of knowledge about urban air pollution as documented in the national and international literature, and (3) interviews with Alberta's research community.

The literature review was divided artificially but conveniently into four major categories -- physical/chemical processes, air quality/meteorological monitoring, modelling, and effects/consequences of urban air pollution. The research and monitoring needs identified in these areas will be used to design an urban air quality research program for Alberta. The report also provides an overview of urban air quality research and its status in Alberta.

1. INTRODUCTION

Urban air quality has been identified in recent public surveys (Krahn 1983) as a leading environmenal concern in Alberta. Accordingly, this report was prepared on behalf of the Research Management Division (RMD) to facilitate the identification of present and future research needs in Alberta. The information presented in this report consists of: (1) a synthesis of available information pertaining to Alberta; (2) a summary of the current state of knowledge on urban air pollution as defined in the national and international literature; and (3) recommendations for short- and long-term research needs in Alberta. A list of acronyms and symbols used through the text is provided at the end of this report.

Report sections summarizing the literature review are artificially, but conveniently, divided into four major categories within the urban air pollution context. These are: (1) physical/chemical processes; (2) air quality/meteorological monitoring; (3) modelling; and (4) effects/consequences of urban air pollution. While this classification was useful for presenting results of the literature review, this segregated approach should not be used when embarking on research programs. Indeed, it is impossible to properly design a meaningful research program without considering all areas of atmospheric sciences collectively. The need for a unified interdisciplinary approach to the understanding of urban air pollution cannot be overemphasized.

The formulation of the recommendations for future research needs in Alberta was largely based on the need to define the quantitative consequences of urban air pollution. An attempt was made to segregate those research needs reflecting Alberta Environment's mandate on the one hand, and the broader national and international concerns on the other. However, a review of various documents dealing with Alberta Environment's mandate failed to provide a clear definition. Therefore, by-and-large, most

deficiencies have been incorporated into the recommendations, except for those research needs that are obviously beyond Alberta Environment's manpower and resources.

The specific recommendations dealing with atmospheric chemical transformations were reviewed by Concord Scientific Corporation of Toronto under contract to ESL Environmental Sciences Limited.

2. STUDY SCOPE AND OBJECTIVES

The terms of reference for this study were defined by RMD and provided for the following tasks to be completed within approximately six weeks:

1. conduct a comprehensive review (utilizing literature provided by RMD) of pertinent information from national/international publications and reports on the processes and consequences of urban air pollution with emphasis on air pollution climatology/meteorology, monitoring, atmospheric chemical transformations, modelling, and effects of urban air pollution; and
2. conduct interviews with representatives from government, industry, and the private and academic communities in Alberta in order to document their past and current research activities and/or interest in urban air pollution and to seek their recommendations for future research needs in Alberta.

The review of the literature was based solely on publications provided by RMD and specific documents obtained during the course of the interviews. No provision was made for ESL to search and retrieve additional information. Documents reviewed and referenced are listed in the References Cited. Other documents, either provided by RMD for review or identified as potentially of interest, are listed separately to provide a more complete bibliographic listing for future reference.

Given these tasks, the study was designed to fulfil the following specific objectives:

1. document the general state of knowledge regarding urban air quality from the literature review;
2. summarize the disposition of urban air quality research in Alberta and assess the province's research within the context of national and international activities; and

3. provide an assessment of future urban air quality research and monitoring needs in Alberta and identify both short- and long-term research and/or monitoring priorities.

3. REVIEW OF ALBERTA URBAN AIR QUALITY LITERATURE

3.1 INVENTORIES OF POLLUTANT EMISSIONS IN ALBERTA

The first attempt to compile an inventory of air pollutant emissions for urban areas in Alberta was conducted by Rolston (1964b) for Edmonton and Rolston (1964a, cited by Tollefson 1972) for Calgary. The significance of various pollutant emissions to future trends in air quality in these cities was briefly discussed by Tollefson (1972).

A comprehensive inventory of air pollutant sources for Edmonton and Calgary was conducted by Western Research and Development Ltd. (1971) on behalf of the Alberta Department of the Environment for the 1971 calendar year. The major objectives of the study were to provide an inventory of all sources and emissions by source and location, present seasonal and geographic distributions, and store the information on magnetic tape for future updating and application to air quality studies. The initial report prepared in 1971 provided only a very limited evaluation of the data acquired. Earl and Beauchemin (1973a, 1973b) provided more detailed statistical and geographical evaluation of the sources, quantities, and types of air pollutant emissions.

A major deficiency in the initial inventory conducted by Western Research and Development Ltd. was the omission of carbon monoxide (CO) emissions from refineries in Edmonton, resulting in an underestimation in annual CO emissions of approximately 152 407 t. The deficiency was corrected and the inventory data base updated to the calendar year 1973 for both Edmonton and Calgary by Alberta Environment (1978a, 1978b). Thus, the only complete inventory of sources and emissions of air pollutants is the data base for the years 1971 and 1973. One of the original objectives for creating the data base was to facilitate continuous updating; however, this was not accomplished since many studies, including the air pollution study by the Planning Department of the City of

Calgary (1978), the analysis of particulate air pollution and visibility over Calgary by Harrison and Mathai (1981b), and the study of particulate matter and aerosols over Edmonton by Klemm and Gray (1982), relied upon data from 1971 and 1973. Consequently, some of the conclusions reported in these studies may not be valid because the emissions data were out of date.

Two other inventories of air pollutant emissions conducted by Alberta Environment are available and could be of some use in urban air quality research. Peters and Sandhu (1980) estimated emissions of nitrogen oxides (NO_x expressed as NO_2) for specific plants in various locations in Alberta. These estimates are based upon stack surveys and extrapolations, and are believed to have an uncertainty of about 20 percent. Existing monitoring of NO_x emissions in Alberta is considered by the authors to be insufficient for computing more precise values.

A similar inventory of sulphur dioxide (SO_2 expressed as sulphur) for the period 1977 to 1981 by Alberta Environment (1982) provides a year-to-year comparison of observed (actual) and licenced emissions from individual industrial operations. A trend analysis of total observed versus licenced sulphur emissions from industrial sources from 1974 to 1981 indicates that actual emissions remained well below licenced emissions. While emissions from coal-fired plants increased over the period 1977-81, emissions from the sour gas industry over the same period decreased, and total emissions from all industries show only small annual fluctuations.

An assessment of the impact of residential wood burning emissions on urban air quality in Canada was conducted by Stuart (1983) for the federal government. The study combined estimates of emissions with meteorological characteristics to derive pollutant dispersion patterns. Wood use data for urban centres was compiled by the Department of Energy, Mines and Resources, and a model was used to estimate probable emission levels. The urban centres were ranked according to potential impact on air quality due to wood

burning, exclusive of any consideration of existing pollutant concentration levels. No urban centres in Alberta were highly ranked by Stuart as potential problem areas.

A national inventory of air pollutant emissions is also available (Environment Canada 1981a). However, the emission data for each pollutant are presented on a 127 km by 127 km grid, which renders them of little value to urban studies.

In summary, the present information on air pollutant emissions in urban areas is composed of a data base for Edmonton and Calgary which is 12 years out of date, and more recent inventories of sulphur (1977-81) and nitrogen oxides (1976-79) emissions from major industrial point sources in or near urban areas. Recent emission estimates for major pollutants such as carbon monoxide, hydrocarbons, and particulates do not exist for urban areas. Furthermore, no estimates whatsoever exist of emissions of minor pollutants such as hydrogen fluoride (from fertilizer plants), toluene (from paint solvents), and ammonia (from fertilizer and chemical plants), all of which may have significant toxic effects on human health.

However, the Pollution Control Division of Alberta Environment is currently updating emission inventories for the cities of Calgary and Edmonton and their report will be available in 1985. These inventories will encompass all five classical pollutants (sulphur oxides, nitrogen oxides, carbon monoxide, hydrocarbons, and particulates) and document all assumptions and emission factors used in order to facilitate future updates. Nevertheless, these inventories are based on 1981 and 1982 traffic statistics for the cities of Calgary and Edmonton, respectively, thereby rendering the yet-to-be published report somewhat out of date. The time lag of two to three years required to produce an updated inventory appears to indicate the need for a more efficient method of maintaining emission inventories.

3.2 AIR QUALITY MONITORING DATA BASE

3.2.1 National/Provincial Air Quality Standards

The Environmental Protection Service (EPS) has established a set of national air quality objectives to provide guidelines for air pollution monitoring programs across Canada. The National Ambient Air Quality Objectives (NAAQO), presented in Table 1, are divided into three levels. The maximum desirable level defines the long-term goal for air quality and provides a basis for an anti-degradation policy in unpolluted areas of the country. The maximum acceptable level is intended to provide adequate protection against effects on soil, water, vegetation, materials, animals, visibility, and personal comfort and well-being. The maximum tolerable level denotes concentrations of air contaminants that require abatement without delay to avoid further deterioration in air quality that may endanger or pose a substantial risk to public health.

Various provincial government agencies in Canada have adopted aspects of the NAAQO for air quality standards within their jurisdictions. Alberta Environment, for example, uses a combination of the NAAQO maximum acceptable and maximum desirable levels for its standards (Table 2), but does not consider the NAAQO maximum tolerable levels in assessments of recorded air pollution concentrations.

3.2.2 Air Quality Monitoring in Alberta

With the exception of occasional air quality studies of specific air pollutants, the collection and assessment of existing air quality data and the determination of long-term trends in urban areas is generally the responsibility of Alberta Environment. To achieve these goals, the Pollution Control Division of Alberta Environment operates a network of ambient air monitoring stations in the cities of Edmonton and Calgary. The network in each city comprises three continuous air monitoring stations (representative

Table 1. National ambient air quality objectives.[a]

Pollutant	Averaging Time	Units	Maximum Desirable	Maximum Acceptable	Maximum Tolerable
Sulphur Dioxide (SO_2)	Annual	$\mu g/m^3$ *	30	60	-
		pphm **	1.1	2.3	-
	24 h	$\mu g/m^3$	150	300	800
		pphm	6	11	31
	1 h	$\mu g/m^3$	450	900	-
		pphm	17	34	-
Nitrogen Dioxide (NO_2)	Annual	$\mu g/m^3$	60	100	-
		pphm	3.2	5.3	-
	24 h	$\mu g/m^3$	-	200	300
		pphm	-	11	16
	1 h	$\mu g/m^3$	-	400	1000
		pphm	-	21	53
Ozone (O_3)	Annual	$\mu g/m^3$	-	30	-
		pphm	-	1.5	-
	24 h	$\mu g/m^3$	30	50	-
		pphm	2	3	-
	1 h	$\mu g/m^3$	100	160	300
		pphm	5	8	15
Carbon Monoxide (CO)	8 h	$\mu g/m^3$	6000	15000	20000
		ppm ***	5	13	18
	1 h	$\mu g/m^3$	15000	35000	-
		ppm	13	30	-
Total Suspended Particulates (TSP)	Annual	$\mu g/m^3$	60	70	-
	24 h	$\mu g/m^3$	-	120	400

* Micrograms per cubic metre
** Parts per hundred million
*** Parts per million
a Conditions of 25°C and 101.32 kPa are used to convert $\mu g/m^3$ to ppm or pphm.

Table 2. Provincial ambient air quality standards.

Pollutant	Averaging Time	Units	Ontario	Saskatchewan	Alberta	British Columbia		
						Level A	Level B	Level C
Sulphur Dioxide (SO_2)	Annual	$\mu g/m^3$ *	55	30	30	25	50	80
		pphm **	2	1	1	-	-	-
	24 h	$\mu g/m^3$	275	150	150	160	260	360
		pphm	10	6	6	-	-	-
	1 h	$\mu g/m^3$	690	450	450	450	900	900
		pphm	25	17	17	17	34	34
Nitrogen Dioxide (NO_2)	Annual	$\mu g/m^3$	-	100	60	NONE SET		
		pphm	-	5	3.1			
	24 h	$\mu g/m^3$	200	200	200			
		pphm	10	10	11			
	1 h	$\mu g/m^3$	400	400	400			
		pphm	20	20	21			
Ozone (O_3)	Annual	$\mu g/m^3$	-	-	-	NONE SET		
		pphm	-	-	-			
	24 h	$\mu g/m^3$	-	30	30			
		pphm	-	1.5	1.5			
	1 h	$\mu g/m^3$	165	100	100			
		pphm	8	5	5			
Carbon Monoxide (CO)	8 h	$\mu g/m^3$	15 700	6 000	6 000	5 500	11 000	14 300
		ppm ***	13	5	5			
	1 h	$\mu g/m^3$	36 200	15 000	15 000	14 300	28 000	35 000
		ppm	30	13	13			
Suspended Particulates (TSP)	Annual	$\mu g/m^3$	60	70	60	60	70	75
	24 h	$\mu g/m^3$	120	120	100	150	200	260

* Micrograms per cubic metre
** Parts per hundred million
*** Parts per million

of downtown, residential, and industrial areas) that collect data on oxides of nitrogen, ozone, carbon monoxide, sulphur dioxide, and total hydrocarbons, and a number of static and intermittent air monitoring stations in various locations that sample total dustfall, total sulphation, and suspended particulate matter.

This network has been in operation since 1973. The annual reports from this network provide summaries of annual and mean monthly concentrations of all pollutants, as well as comparisons with air quality standards.

Prior to 1973, Alberta Environment operated a different network of stations. A major revision and expansion of stations occurred after 1973. Dobko et al. (1971) provided a summary of data from the earlier network for the period 1964 to 1971.

3.2.3 Pollutant Concentrations Recorded in Edmonton and Calgary

Lack (1969) compared levels of dustfall, hydrogen sulphide, total sulphation, suspended particulate matter, and total oxidants in Edmonton and Calgary during the period December 1967 to May 1969. The author concluded that it was not possible to make specific statements concerning the overall relative air pollution levels in the two cities because the recorded levels were highly dependent upon the location of monitoring stations and on local sources of pollutants in the vicinity of the stations.

More recently, the annual summary reports of air monitoring in Edmonton and Calgary have noted that the levels of recorded concentrations of various pollutants on many occasions exceed the provincial air quality regulations for all pollutants except sulphur dioxide. The monitored levels of NO_2 in Calgary indicate that daily averages in the range of 0.06 to 0.11 ppm (the range considered harmful to individuals suffering from respiratory ailments) were reported periodically, particularly during fall and winter months, at all three continuous monitoring stations during the period 1975-79. Similarly, recorded levels of ozone are

sufficiently high to "affect sensitive vegetation, materials, and individuals predisposed to chronic pulmonary disorders" (Alberta Environment 1979:10). High levels of both carbon monoxide and hydrocarbons in the downtown area during the fall and winter seasons are attributable to the combination of high vehicular traffic density and meteorological factors that decrease dispersion of emissions. The levels of suspended particulates regularly exceed air quality standards. In some locations there are concentrations of suspended particulates that are sufficient to constitute a nuisance, affect materials, and may, in conjunction with low levels of sulphur dioxide, present a health hazard to some individuals.[1]

Recorded levels of pollutants in Edmonton are somewhat lower than in Calgary, but the same general comments are applicable. These comments should not be construed as implying that a severe air quality problem exists in the cities of Edmonton and Calgary. However, various studies that have compared pollutant concentrations recorded in Canadian urban areas have indicated that the levels recorded in Edmonton and Calgary are comparable to levels recorded in much larger cities, and at times exceed tolerable limits for specific pollutants. For example, Paproski and Walker (1974) showed that Edmonton and Calgary had the highest frequencies of exceedence of 24-h NO_2 standards in the country during 1973, and that Calgary ranked second only to Toronto for exceedence of CO standards. Similarly, Ricci et al. (1978) ranked Calgary as having the highest annual average NO_2 index for any city in Canada during 1974 and 1975. Compared with the average of annual means of National Air Pollution Surveillance (NAPS) stations for 1979 (Environment Canada 1981b), the recorded levels of ozone, carbon monoxide, nitrogen dioxide, and suspended particulates for Calgary and Edmonton were

---

1 The harmful effects of various pollutants are discussed in Section 4.4

well above average for Canadian urban areas. One station in Calgary was the only site in the NAPS network to record an exceedence of the NO_2 maximum tolerable 1-h level in 1979 (Environmental Protection Service 1981c). Calgary, Toronto, and Quebec City were the only sites in Canada reporting CO values in excess of the maximum tolerable 8-h level in 1979, and one station in Calgary had the highest annual mean ozone levels in Canada. In 1980, Calgary recorded the highest level of suspended particulates of all NAPS stations, even exceeding levels at the worst of three locations in Montreal. In fact, concentrations of particulates occasionally exceed 24-h tolerable levels of national air quality objectives in Calgary, and the high levels may be attributed to the re-entrainment of dust from unpaved roadways and construction projects (Environmental Protection Service 1981c). Concentrations of CO also exceeded 8-h tolerable levels at one NAPS station in Calgary during 1980, although the present method of reporting the incidence of exceedence does not provide sufficient information to determine the frequency and duration of exceedences of tolerable levels.

The following section provides a summary of the data base for each of the classical pollutants monitored in Edmonton and Calgary.

3.2.3.1 Oxides of Nitrogen. An early investigation into the formation of smog in Edmonton and Calgary by Tollefson (c. 1970a and c. 1970b) compared the levels of nitrogen oxides in these two cities for 1969 with those reported in Los Angeles for 1962. Tollefson reported that the average concentrations observed in Edmonton fell within the range required to form photochemical smog. In addition, Calgary's monthly averages of the maximum daily concentrations of nitrogen oxides corresponded closely with those recorded in Los Angeles and were sufficient for the formation of photochemical smog.

In 1976, an attempt was made to investigate the use of a remote sensing Correlation Spectrometer (COSPEC) for mapping the

horizontal distribution of NO_2 burden on selected days in Edmonton and Calgary (Klemm 1977a). In addition, the instrument was to be used to determine the width and maximum downwind extent of travel of the Calgary and Edmonton urban plumes, and to trace the trajectories of NO_2 plumes from a number of industrial sources. The field measurements failed to find significant amounts of NO_2 in any of the plumes investigated, and this was attributed to meteorological conditions that favoured rapid dispersal. The study did, however, enable the investigators to gain familiarity with the operation, capabilities, and limitations of the COSPEC as an NO_2 sensor. No follow-up studies to the use of COSPEC have since been conducted in Alberta and, according to Dr. Klemm, the COSPEC technology is now considered to be outdated for such purposes.

In a preliminary investigation of NO_x concentrations in the exhaust plume of a natural gas compressor station located 50 km north of Edmonton, Angle, Sandhu, and Schnitzler (1978a, 1978b) observed that the ratio of NO_2 to NO_x increased by a factor of seven above its value in the exhaust stack within one minute of plume travel time from the stack. The observed values were significantly lower than those predicted by a theoretical photochemical reaction model developed by Bottenheim and Strausz (1978). The relatively high regional background levels of NO_x recorded during the study suggested the possibility of downwind urban plume transport of pollutants from metropolitan Edmonton.

A comprehensive review of current knowledge and understanding of the environmental impact of nitrogen oxides and their photochemical derivatives was reported by Legge et al. (1980). The authors placed special emphasis upon the relationship of current knowledge about NO_x to specific environmental conditions in Alberta. It was noted that concentrations of NO_x, as monitored in Calgary and Edmonton by Alberta Environment, are among the highest in Canada during the winter months, and are attributable to high traffic density and stable meteorological conditions during winter.

In addition, the authors considered the impact of emissions from large point sources, such as thermal power plants near urban areas, to be a special source of concern in Alberta because industrial emissions account for approximately one-half of the nitrogen oxides emitted in Alberta.

Although NO_2 is generally recognized to be a health hazard today, Legge et al. (1980) reported that overall very little work with pollutant admixtures involving oxides of nitrogen has been undertaken.

3.2.3.2 Ozone. Ozone concentrations in the atmosphere of Calgary and Edmonton have been studied in conjunction with investigations of photochemical transformations of pollutants and as part of several of the previously mentioned studies on oxides of nitrogen. For example, Legge et al. (1980) provided a brief summary of ozone measurements in Alberta and compared observed levels with those recorded in other cities in Canada. They conclude that, although ozone concentrations do periodically exceed air quality standards of 50 ppb, Alberta cities generally have low ozone concentrations as compared with other Canadian cities.

Sandhu (1975) examined photochemical air pollutants and meteorological variables for the urban airsheds of Edmonton and Calgary. The study revealed that high levels of ozone in the summer months prevail in the "pollution dome" over the downtown area under calm and stable atmospheric conditions. The author concluded that the only logical way of minimizing and controlling photochemical air pollution would be to reduce concentrations of both nitrogen oxides and hydrocarbons produced by the two main sources of emissions, namely, vehicular traffic and industries. An extensive list of recommendations was provided by Sandhu, many of which have already been adopted by Alberta Environment. Noted among these recommendations was the need to determine background ozone levels in Alberta. A study by Sandhu (1976) of background oxidant/ozone

concentrations suggested that ozone precursors may be produced in large quantities in rural areas during summer months as a result of convective thunderstorm and hailstorm activity, and subsequently advected to urban areas. While observed oxidant/ozone concentrations in Edmonton and Calgary during the winter months remain below the provincial air quality standard of 5 pphm for hourly concentrations, ozone levels above 5 pphm were recorded on almost every sunny day during the summer months in Edmonton.

A recent study of ozone in Alberta conducted by Peake and Sandhu (1983) examined, for the first time in Alberta, the photochemical formation of ozone and peroxyacetyl nitrate (PAN) in Calgary. Peak concentrations of PAN coincided with the afternoon peak in ozone concentrations. It was concluded that in Calgary the limiting factor in the formation of PAN during winter is solar radiation. In the summer months, on the other hand, the abundance of primary pollutants (i.e., nitrogen oxides, carbon monoxide, and hydrocarbons), which are the precursors of PAN, determines the rate of formation of PAN in Calgary. It was suggested that, during the spring and autumn months, the possibility exists for the simultaneous occurrence of high levels of pollutants together with high solar radiation and temperatures, resulting in the generation of PAN in the atmosphere over Calgary. A significant aspect of the study was the confirmation of the findings with modelling studies previously reported by Bottenheim et al. (1977).

In a second study, Peake, MacLean, and Sandhu (1985) reported that PAN is the major reaction product of nitrogen oxides in the cold, dry, continental climate of Calgary. Concentrations of PAN, nitric acid, and particulate nitrate together account for an average of eight percent of the total nitrogen-containing compounds in the atmosphere over Calgary. It was concluded that the range of particulate nitrate concentrations in Calgary was comparable on average to that of other Canadian cities, although brief episodes of higher than average concentrations may occur when stable atmospheric conditions coincide with the early morning rush-hour traffic period.

3.2.3.3 Carbon Monoxide (CO). A study to determine the significance to public health of outdoor and indoor exposure to CO in Calgary was conducted by Smith et al. (1974) and submitted as part of a Ph.D. thesis by Smith (1975). Indoor and outdoor levels of CO were measured in the central business district and at the suburban campus of the University of Calgary. As well, a special case of indoor exposure among parkade employees was examined in the initial study and was extended to four other occupations (bus and taxi drivers, policemen, and parking ticket officers).

The conclusions resulting from these studies indicated that, although the concentrations of CO in the central business district of Calgary are not as high as in the worst areas for CO pollution in North America (i.e., Los Angeles, Chicago, and Denver), street level concentrations in Calgary exceeded the Alberta 8-h standard of 5 ppm on 23 of 24 test days. Furthermore, the studies showed that the CO levels recorded by the monitors operated by Alberta Environment and situated on building rooftops were not indicative of street level CO concentrations. It was estimated that, on average, pedestrians in the central business district were exposed to CO levels three times higher than were recorded by the downtown Alberta Environment monitor. According to Smith (1975), late afternoon levels of 35 to 40 ppm CO at street level were frequently observed for up to two hours, with peak hourly levels of 72 ppm. Peak CO levels measured at street level, inside buses and automobiles, inside parkade ticket booths and auto repair areas, and on the ground floors of unsealed buildings in downtown Calgary were sufficiently elevated to be a health hazard to older persons with latent heart disease.

Smith et al. (1974) recommended that a method be established for detecting long-term health effects in automobile-related occupations in Calgary. Other recommendations included the revision of ventilation requirements for automobile parkades and the screening of applicants for employment in parkades for any heart disease.

Although a number of studies have examined data from the air quality monitoring network in relation to meteorological parameters, specific research on CO concentrations in Edmonton is mainly limited to a series of measurements within the North Saskatchewan River Valley by Hage (1979) and Hage and Hopps (1982b). The purpose of these studies was to examine the influence of a small urban valley on air pollutant concentrations during clear nights with light winds. Simultaneous measurements of air temperatures and winds were used to define meteorological influences on pollutant concentrations.

The results of these studies indicated that the valley behaved in a predictable manner, storing CO from late afternoon and early evening emissions and releasing it slowly at night. The highest concentrations measured within the valley were more than double the concentrations measured in downtown Edmonton. However, valley wind systems often develop within the inversion and serve to stretch the pollutant plumes along the valley, thereby reducing local concentrations.

Although the CO levels observed in the valley were below the regulation limit of 13 ppm for hourly mean values in all cases, it must be noted that these experiments were conducted in conditions that were not representative of worst case atmospheric inversions. Due to equipment problems at temperatures below freezing, no measurements have been undertaken in wintertime inversions when wind systems within the valley may be an insignificant factor for dispersion. Hage and Hopps (1982b) make two recommendations for future research: (1) that additional measurements of CO concentrations be taken in the spring, fall, and winter; and (2) that future measurements of CO concentrations and meteorological variables include simultaneous observations of not less than four stations, supplemented by vertical profiles of CO levels, wind, and temperatures in order to improve the data base for interpretations.

3.2.3.4 Sulphur Compounds. Beyond routine monitoring of sulphur dioxide, total sulphation, and sulphate particles in rain, no research into sulphur compounds in an urban atmosphere has been conducted in Alberta. However, a review of sulphur research in Alberta by Sandhu et al. (1980) included research reports of effects of sulphur on human health and corrosion of materials in relation to industrial sulphur emissions. Some of the literature reviewed by Sandhu et al. (1980) could be useful in considering the impact on urban centres of sulphur emissions from upwind industrial locations.

The lack of significant research on sulphur in urban atmospheres in Alberta may be due to the generally lower concentrations of sulphur oxides detected during routine monitoring. Recorded levels of sulphur dioxide measured by the stations of the Air Quality Monitoring Network in Edmonton and Calgary are low in comparison with other major Canadian urban areas. For example, SO_2 concentrations at all NAPS network stations in Calgary and Edmonton during 1980 met desirable objectives of the NAAQO, whereas stations in other urban areas such as Montreal and Toronto often exceeded acceptable and desirable levels for annual, 1-h and/or 24-h concentrations. Therefore, the need for extensive research on sulphur in urban atmospheres in Alberta is not as pressing as in other provinces.

Sulphate in rain is currently monitored in Calgary, Edmonton, Red Deer, Whitecourt, Lethbridge, Coronation, Edson, and Rocky Mountain House. According to Klemm (1977b), the pH of rain in central Alberta is still typical of non-industrial environments, in contrast with areas of eastern North America and northern Europe. The median pH of rainfall in Alberta is about ten times less acidic than rainfall in industrial regions (Klemm and Gray 1982). Klemm (1977b) attributes the high values of SO_4 observed in the rain in Calgary to the poor choice of location for the rain collector, i.e., adjacent to major runways of the international airport.

Klemm and Gray (1982) analysed the chemical composition of rainfall within a 30 km radius of Edmonton during the summers of 1977 and 1978. The samples of rainfall were analysed for pH, conductivity, and 22 ionic species. Median observed pH for individual precipitation events ranged from 4.4 to 5.8. Acidic rain was found at all sites south of Edmonton city centre. Analysis of surface winds indicated that the rainfall in these events had originated in air masses that had passed over the Edmonton metropolitan area. The ionic composition of the rainfall indicated that the low pH was related to reduced buffering capacity resulting from "low concentrations of calcium species, rather than the presence of large amounts of nitrate and sulphate species". Relatively higher concentrations of nitrates and sulphates in rainfall north of Edmonton city centre "were not associated with lowered pH values because the acidic component was neutralized sufficiently by correspondingly elevated concentrations of basic calcium and ammonium species".

As part of the same study, Klemm and Gray (1982) examined rainfall events in a broad area from west of Rocky Mountain House to east of Red Deer. In the analysis of the ionic composition of these events, the concentrations of suspended particulate species appeared to exert a dominant influence on determining rainfall pH. The authors noted that the pH at any time in a storm consists of a combination of chemical and physical parameters that may not be evident from bulk sample data alone. The ionic composition of rainfall samples collected sequentially during a single storm event showed that:

1. there was a progressive decrease of calcium (and by inference other suspended particulates);
2. there were essentially constant concentrations of sulphate, nitrate, chloride, ammonium, potassium, sodium, and magnesium; and

3. there was an abrupt decrease in pH during the storm, which was paralleled by the increase in nitrate (probably generated by the storm activity).

Although ambient air monitoring data indicate low concentrations of SO_2 in Edmonton and Calgary, fugitive dust from local soils has been identified as a source of high concentrations of suspended particulates in Edmonton (Klemm and Gray 1982). It is possible that increasing precipitation acidity in these urban areas could occur even with comparatively low levels of sulphates in ambient air if the composition of suspended particulates is deficient in basic compounds. Therefore, it would appear that the chemistry of precipitation in urban areas in Alberta warrants continued study to assess the role of terrestrial sources of particulates in wet deposition processes. Of particular interest would be a study of the effects of agricultural fertilizers on the chemical composition of fugitive dust.

3.2.3.5 Hydrocarbons. Peake and Black (1975) conducted a project designed to detect and measure the exposure of the human population of Calgary to known carcinogenic polycyclic aromatic hydrocarbons (PAH) in the atmosphere. They determined that small but significant amounts of carcinogenic hydrocarbons were present in the ambient air in Calgary as a result of automobile emissions. Downtown street levels were five to seven times higher than those of suburban residential areas, reflecting differences in traffic density. Under average wind conditions, rapid mixing and dispersion of PAH pollutants in the downtown area reduces concentrations at the third-floor building level to between one-third and one-fourth of concentrations at the street level. Peake and Black questioned the representativeness of hydrocarbon concentrations measured by the Air Quality Program monitoring stations located in the downtown area for assessment of human exposure at street level.

Peake and Parker (1979) continued the investigation of carcinogenic hydrocarbons in Calgary, and concluded that the "carcinogenic activity of the Calgary atmosphere (measured as mutagenicity in the Ames Test) is equivalent to that of California cities such as Fresno, Riverside and Sacramento, but far less than that of an industrialized Japanese city. The atmosphere contains more than 170 polynuclear aromatic hydrocarbons, at least eight heterocyclic sulfur compounds and two oxygenated polycyclic compounds. Six carcinogenic aromatic hydrocarbons were identified and the presence of many more carcinogenic alkylated aromatics was indicated". The authors noted that benzo(a)pyrene, which is often used as an indicator of the carcinogenicity of urban air, accounted for only a small part of the mutagenic activity of air in Calgary. They concluded that unidentified direct acting mutagens were responsible for most of the mutagenicity in Calgary air, while total polycyclic aromatic hydrocarbons accounted for less than 50 percent of the observed activity.

A study by Das and Howrish (1980) was conducted in the vicinity of the Celanese chemical plant in Edmonton in order to identify the volatile organic compounds in the ambient air. Ten organic volatile compounds were identified, of which some exceeded the odour threshold limit for almost every month of the year. The identified aromatic compounds are known to be toxic, while the acidic compounds constitute a major source of public complaints about odour.

Another study to assess the impact of specific emissions from the Strathcona industrial area on the Clareview district of Edmonton (Alberta Environment 1981) determined that levels of benzo(a)pyrene, a known carcinogenic hydrocarbon, were higher in the Clareview district than in the downtown and residential areas of Edmonton (but were comparatively lower than in other cities). However, the results of the survey were inconclusive because correlations of pollution levels with prevailing wind directions

indicated that sources other than the major industries in Strathcona were contributing to these levels.

Strosher (1982) conducted an air quality study of organic compounds to examine both the methods of detection and the ultimate occurrence of any trace contaminants in the atmosphere near industrial operations in Alberta. Air samples were collected from the gas processing operations in the Pincher Creek area, in the vicinity of a food processing plant near Fort Saskatchewan, and from a wood treatment facility in Cochrane. The results of the study indicated that a wide variety of organic compounds ranging from the very volatile components to the much larger and less volatile constituents, such as PAH, can be collected efficiently on traps filled with specific adsorbents and individually identified in the laboratory by combined gas chromatography and mass spectrometry. The study revealed a potentially useful technique for the examination of airborne contaminants, especially with respect to evaluating their relationship to any human health problems near industrial development.

In conjunction with the study by Strosher (1982), Sciex™ (1982) conducted a second program of monitoring airborne trace organic compounds using the TAGA 3000 mobile monitoring system. The overall purpose of the study was to demonstrate the utility of the TAGA system for qualitatively identifying pollutants in ambient air as well as tracking and quantification of specific chemical compounds in the vicinity of various industrial sites in Alberta. The results of the study identified a large number of trace compounds at the monitoring sites, thereby successfully demonstrating the extreme sensitivity of the TAGA system for detecting ultra-trace concentrations. However, because of the limited nature of the demonstration program, conclusive interpretation of the data with regard to characterization of ambient air quality at the sampling sites was not attempted, and it was recommended that further studies focussing on specific chemical compounds be conducted in future.

A review of the two studies of Strosher (1982) and Sciex™ (1982) was conducted by a committee of scientists (Hrudey et al. 1983). It was concluded that both studies demonstrated the inherent ability of the methods to perform such measurements, but that conclusive assessment of the data with regard to environmental quality or public health concerns was not possible since neither study was designed for such evaluation.

3.2.3.6 Particulates. A preliminary investigation of atmospheric particulate matter and aerosols in Calgary by Peake (1980) established that relatively high concentrations of nitrate, sulphate, and ammonium ions may be present in the atmosphere where wind speeds are low and from the southeast. Samples collected by aircraft identified the existence of an urban plume of pollutants downwind from Calgary even on days with only moderate winds. It was recommended that further studies of particulates in Calgary be continued on a regular basis in order to establish annual concentration means, seasonal and diurnal variations, and the effects of topography on concentration levels.

A study to determine the particle size distribution of ambient aerosols in relation to visibility in the Calgary boundary layer was conducted by Harrison and Mathai (1981b). The study used nephelometer, cascade impactor, high volume samplers, acoustic sounder monitoring, and COH, NO_x, O_3, CO, and HC sampling. Through comparisons of the aerosols in the industrial sector of Calgary with those in the residential sector, it was inferred that emissions from industrial activity inject more large particles into the atmosphere than do corresponding residential emissions. A significant result of monitoring through chinook and temperature inversion events was that the particle size spectrum changed signficantly, accompanied by corresponding changes in the aerosol scattering coefficient and meteorological parameters. However, the authors noted that a definition of the chinook condition, together

with a thorough understanding of its effects on urban air quality, remains a matter of controversy among various investigators. Although interest in the chinook phenomenon with respect to the Calgary urban environment has been expressed by investigators throughout the 1960s and 1970s, relatively little is known of the resulting effects of the chinook on aerosol particle size distribution, chemical properties of aerosols, visibility, and the like. Among the recommendations made by Harrison and Mathai (1981b) for future research are studies involving particle size distribution, nephelometer, acoustic sounder, visibility (using telephotometry), and meteorological measurements utilizing a continuous and prolonged monitoring program of chinook and temperature effects in Calgary. The Department of Physics at the University of Calgary has conducted a large number of studies on these topics, the results of which have been reported by Harrison (1977, 1978, 1979a, and 1979b), Harrison and Mathai (1979), Harrison and Pi (1980), Mathai, Harrison, and Mathews (1980), Mathai and Harrison (1980), Harrison and Mathai (1981a), Coombes and Harrison (1982), Mathai and Harrison (1982), Harrison and Lant (1982), and Harrison and Murdock (1982).

A study by Grandia (1981) of the feasibility of using airborne particulate sampling of the urban plume downwind of Calgary demonstrated the utility of this method for correlating surface and airborne concentrations. It was suggested that this method could be used to obtain pollutant concentrations upwind and downwind of urban areas in order to verify the extent and geometry of the urban pollution dome and urban plume behaviour, to identify local pollutant sources and sinks, and to relate these to upwind concentrations. The report recommends the inclusion of periodic airborne pollutant sampling in the current provincial air quality monitoring programs.

Maksylewich (1974) conducted preliminary investigations into the extent of automobile-derived lead aerosols within the city

of Edmonton. Mean monthly atmospheric lead concentrations ranged from 0.06 $\mu g/m^3$ for a residential area to 0.7 $\mu g/m^3$ for a downtown location. Maksylewich estimated that mean daily concentrations of lead aerosols in Edmonton would be of the order of 3 $\mu g/m^3$ near heavy automobile traffic. This would have been approximately twice the then permissible standard established for California. Maksylewich doubted the representativeness of lead levels monitored at the downtown fixed monitoring station, and recommended further studies into lead concentration in air, water, soil, and vegetation in the vicinity of roadways.

A study of the chemical composition and seasonal variability of airborne particulates in the Edmonton airshed was reported by Klemm and Gray (1982). Based upon a program of three 28-day sampling periods during spring, summer, and fall, and a review of available literature, the authors concluded that the majority of total suspended particulates in Edmonton is soil-derived material from local sources. Particulate levels in excess of Alberta daily air quality standards occurred one day in four during both the fall/winter and winter/spring sampling periods and on 17 of 28 days in summer. It was concluded that the geographical and meteorological conditions of the Edmonton area make it difficult to consistently meet the air quality standards. A recommendation was made that the standard for particulates be reviewed in light of these findings.

Other significant findings of the study by Klemm and Gray (1982) identified elevated levels of lead from vehicular emissions within Edmonton and at Stony Plain in association with east winds, which suggests medium-range transport of Edmonton aerosols to Stony Plain. Occasionally, lead concentrations in Edmonton reach levels equal to or even surpassing those reported in much more densely populated cities. The presence of enhanced levels of other heavy metals under conditions of low ventilation and specific wind direction indicated the influence of industrial emission sources. It was noted, however, that for those variables measured in common

with Alberta Environment monitoring sites (notably total suspended particulates and lead), significant differences in concentrations were observed. These differences were considered by Klemm and Gray to be in excess of reasonable experimental errors. The authors recommended that a regular schedule of sample exchanges between Alberta Environment and other analytical or sampling agencies be instituted to facilitate comparison of results from different monitoring studies. Furthermore, it was recommended that the criteria used in arriving at monitoring site selection by Alberta Environment be clearly set forth in further air monitoring reports of Alberta Environment.

Recently several studies have examined the concentrations of peroxyacetyl nitrate (PAN) in the city of Calgary. Peake (1983) reported that the highest concentrations were observed to occur in downtown Calgary. The maximum recorded concentration was 6.0 ppb, "far below the peak of 65 ppb recorded in Los Angeles, California". (Peake 1983:xiii) However, the mean daily maximum of 0.6 ppb during the eight-month study was similar to levels observed in other urban areas in North America, excluding California. "Particulate nitrate and nitric acid concentrations in Calgary were low compared with other North American cities, but during occasional pollution episodes, high concentrations, up to 29 $\mu g/m^3$ nitrate and 41 $\mu g/m^3$ sulphate were found" (Peake 1983:xiii).

Peake and Sandhu (1983) examined the formation of PAN and ozone in photochemical reactions in the atmosphere over Calgary (see subsection 3.2.3.2), while Peake, MacLean, and Sandhu (1983) reported on the background levels of ozone and PAN at remote locations approximately 70 km west of Calgary. Peake (1983) and Peake and Sandhu (1983) identified low intensity and duration of solar radiation as being the primary limiting factor for PAN formation in the winter months, and lack of primary pollutants in urban atmospheres as the limiting factor in summer. However, infrequently high levels of PAN in the Kananaskis Valley were

attributed to smoke plumes from forest fires at distances of 350 km north of the Valley (Peake, MacLean, and Sandhu 1983), thus establishing the possibility of medium-range transport of PAN from natural sources to urban areas.

3.3 METEOROLOGICAL MONITORING

The following subsections deal entirely with studies conducted in either Edmonton or Calgary, the sole purpose of which was to examine the physical atmospheric processes related to meteorological parameters such as wind, temperature, and turbulence. Many other studies mentioned in other sections of this report have described meteorological observations resulting from their pollutant monitoring programs, or modelling of pollutant dispersion. Those studies will not be discussed here as the meteorological data in those studies were essentially used to explain observed or calculated levels of pollutants and not to describe physical atmospheric processes. However, some of the data recorded for those other studies could be of interest in planning future studies of urban climatology.

3.3.1 Temperature and the Urban Heat Island

The horizontal and vertical variation of the urban temperature field has been described in numerous studies conducted in both Edmonton and Calgary. Munn and Emslie (1964) examined the frequency and intensity of early morning ground inversions at Edmonton during 1950 to 1960. A second study by Munn et al. (1970) for the period 1965 to 1968 noted that synoptic weather patterns common in autumn and winter in Alberta produce stagnant atmospheric conditions that have serious potential for elevated air pollution episodes. Angle (1983) has reported that, in 1966, concern about smoke levels and reduced visibility in low temperature fog induced the government of Alberta to commission the installation of wind and temperature sensors at different levels on towers and buildings in

both Edmonton and Calgary. The results of this monitoring program, conducted from 1968 to 1970 (Geoscience Research Associates 1969, 1970), were summarized by Angle (1983), and Angle reports that a five-year summary of more recent instrumented tower data is soon to be published by Alberta Environment.

A number of studies by graduate students (Daniels 1965; Djurfors 1969; Berry 1970) at the University of Alberta have examined various aspects of the urban temperature field in Edmonton. Daniels (1965) obtained a series of temperature traverses through the city and found significant temperature increases only at the city's built-up area and at the borders of the central business district. Djurfors (1969) analysed the structure of the urban heat island in Edmonton from horizontal temperature traverses and instrumented towers and thermograph networks, and observed that the urban heat island in Edmonton is divided into at least two parts by the valley of the North Saskatchewan River. Berry (1970) examined long-term urban/rural temperature contrasts in Edmonton over the period 1931 to 1965 and estimated an increase of 2.2°F (1.2°C) for minimum temperatures and 0.7°F (0.4°C) for maximum temperatures in Edmonton. However, Berry's use of temperature data from the airport located some distance from the centre of the city raises doubts about the representativeness of the findings of urban heat island effects.

Urban/rural contrasts in temperature and humidity in Edmonton were also examined by Hage (1975) for the years 1961 to 1966 and 1967 to 1973. Hage concluded that urban/rural moisture differences did not play a crucial role in the development of the urban heat island effect. However, the author also stated that it was difficult to determine the relative importance of water vapour sources, sinks, and transfer processes to time changes in urban temperature and humidity without better resolution of rural and urban temperature and moisture profiles in the lowest 50 m, and without including all of the physical processes of horizontal advection, radiative flux divergence, and vertical turbulent flux divergence in the computations.

A short term, intensive field study of temperature, wind, and air quality data was conducted in Edmonton in November and December 1974, in conjunction with the development of an urban air quality model (Angle and Torneby 1975). Vertical temperature profiles were obtained using minisondes and instrumented helicopter flights, and a preliminary analysis of the data was produced by Yap (1975).

More recent measurements of air temperatures in Edmonton have been conducted in association with measurements of air pollutant concentrations, particularly within the valley of the North Saskatchewan River, as exemplified by the work of Hage (1979), or in conjunction with modelling studies as by Hwang (1978). In addition, Alberta Environment established a special meteorological station in Edmonton for the specific purpose of providing reliable supporting data for dispersion modelling (Angle and Godin 1979, 1982). A continuously operating SODAR and periodic minisonde soundings provide data on temperature gradients, mixing heights, and atmospheric stability. Additional instrumentation provides standard measurements of pressure, humidity, and precipitation, as well as information on wind profiles, net radiation, and turbulent heat flux.

The urban temperature field in Calgary has received a similar degree of attention over the last two decades. Apart from the previously mentioned temperature traverses conducted by Djurfors (1969), an initial attempt at defining the heat island in Calgary was reported by Yudcovitch (1967). This work was extended and updated by Truch (1977), who observed a change in the surficial temperature field from that reported by Yudcovitch, which Truch associated with changes in the size and structure of the city. The surficial temperature field closely resembled the pattern of heat emissions, and formed a multi-cell heat island. The largest temperature gradients occurred within the city and were attributed to topography, heat emission, and weather conditions, particularly chinooks. Diurnal, weekly, and monthly temperature variations were also examined.

Nkemdirim (1976) conducted investigations into the dynamics of Calgary's urban temperature field in a limited case study of a winter day free of frontal activity. Using helicopter traverses and pilot balloon soundings, as well as a network of surface stations, Nkemdirim showed the multi-celled structure of the heat island at street level, and correlated surface temperature gradients and variations with low wind speeds and strong relief features. Within the urban boundary layer, the distribution of thermal surfaces was displaced in the direction of prevailing winds.

Leggat (1978) used similar data from helicopter measurements, pilot balloons, and instrumented towers to define mean temperature profiles within Calgary's heat island and to describe the effects of topography, wind, and weather systems on stability and mixing depths within the urban boundary layer.

Nkemdirim and Truch (1978) examined the annual patterns of heat island intensity in Calgary. The authors noted the critical importance of the topography of the city to the evolution of the heat island through its influence on windflow patterns in the city. The occurrence of the mid-morning maximum heat island intensity was attributed to trapping of heat, during peak fuel consumption, within a shallow layer near the surface during periods of weak winds. In a discussion of the article by Nkemdirim and Truch, Landsberg (1978) stated that this mid-morning occurrence of peak heat island intensity was quite novel to Calgary, since reports of daytime heat islands in other localities have been confined to mid-day occurrences.

Using data collected in 1976, Nkemdirim (1980b) estimated that in winter cold air drainage from surrounding hills in Calgary effectively reduced the magnitude of the heat island by approximately 40 percent below its potential value, and deepened the thickness of the inversion layer at the city centre by approximately 100 m. An attempt by Nkemdirim (1980a) to model the intensity of the heat island based upon a ratio of temperature lapse rate to wind speed

was less successful than estimates based upon the lapse rate alone at the edge of the city.

Further work on the vertical structure of the urban boundary layer in Calgary was conducted by Mathews and Hicks (c. 1978), who examined the stability of the boundary layer using a monostatic acoustic sounder. A scheme was developed by which the boundary layer could be classified as stable, neutral, or unstable based on acoustic sounder signals. Comparisons were made with an extensive set of radiosonde measurements, and with tethersonde data on selected days. In addition, qualitative interpretations of seasonal and diurnal variations of NO_x concentrations were formulated, indicating that high pollution levels were most frequently associated with inversions. The most severe pollutant build-up was particularly notable in association with calm periods of chinook-associated surface warming.

3.3.2 Surface Winds and Turbulence

The diurnal variation of surface winds at Calgary was first reported by Longley (1968). A shift from northwesterly winds at night to southeasterly winds in the afternoon was attributed by Longley to the effect of the Rocky Mountains west of the city, which have a northwest-southeast alignment. However, this explanation was questioned by other researchers (cited in Longley 1969), and both Western Research and Development (1977a) and Leggat (1978) noted that the diurnal wind variations at Calgary have not been satisfactorily resolved in the scientific literature. Although Nkemdirim (1976) and Mathews and Hicks (c. 1978), as discussed in the preceding sub-section, made use of wind data to some extent in their studies of temperature fields in Calgary, and Nkemdirim (1980a) examined aspects of topographical influences on cold air drainage within the Bow River Valley, the influence of the Rocky Mountains and local topography on the wind field in the city of Calgary has not been well defined.

In contrast, a number of attempts have been made to analyse surface winds in Edmonton. Campbell (1972) examined data from four 3-m towers around the periphery of the city of Edmonton and showed that airflow was directed toward the heat island centre. Hourly maps of horizontal wind (and vertical temperature profiles) were presented, which were representative of five typical synoptic conditions needed for urban induced circulation.

The results of an attempt to measure urban effects on turbulence were reported by Steenbergen (1971), who compared wind observations from an urban and a rural site at Edmonton. Although the author found that the turbulent intensity was more than three times greater at the urban site than at the rural site, the observations were highly site specific. Consequently, the results could not be easily extended to other locations in the city.

A number of studies have focussed on examining the airflow within the North Saskatchewan River Valley. Those that were conducted as part of modelling studies will be reported in subsection 3.4. Paterson (1978) reported on drainage winds on the slopes of the valley. Although Paterson's data were insuffienct to completely describe the valley wind circulation, the potential for pollutant entrapment within the valley was established. Valley winds in relation to pollutant concentrations were also discussed by Hage (1979).

3.3.3 Mixing Heights

The concept of mixing height developed by Holzworth (1967) has been generally accepted as representative of the thickness of the layer of air in which pollutants are well mixed. Hage and Longley (1970) showed that in Edmonton conditions for incomplete vertical mixing often exist, especially during the month of December. Nkemdirim et al. (1975) demonstrated that the diurnal variation and stratification of oxidants within the urban heat island of Calgary were correlated with atmospheric stability and

surface mixing. An increase of pollutant concentration with height was observed to occur in the city with frequency of 60 percent during the summer-fall transition period, usually from late evening to mid-morning.

Longley (1973) examined mixing heights over Edmonton in a study that raised more questions than it answered. Two anomalies were noted with respect to pollution potential that appeared to contradict what was normally expected. While the study showed that Edmonton had frequent periods of low mixing heights, these occurred under meteorological conditions that were not previously considered to be conducive to producing such low mixing levels. A lack of time prevented Longley from examining precise relationships between various meteorological parameters such as wind speed, surface wind direction, cloudiness, and mixing depth, and it was concluded that further study was necessary.

Western Research and Development Ltd. (1976a, 1976b) conducted field studies of temperature profiles in both Calgary and Edmonton as part of the verification stage in the development of an air column trajectory model. Vertical profiles of ambient temperatures, CO, and NO_x concentrations up to 300 m above ground were obtained from helicopter measurements. The studies concluded that the use of the mixing layer concept for the model was valid in both cities.

However, Yap (1975) examined low-level temperature profiles in and around Edmonton using the data obtained by Western Research and Development. The study by Yap showed that urban-induced temperature modification frequently occurred in the lowest 100 m above ground. Within this modified layer, the urban lapse rate exhibited a complex pattern ranging from stable (inversion) to adiabatic. As a result, Yap suggested that the concept of a nocturnal urban mixing depth, with the implication of a more or less uniform vertical distribution of pollutants, was often not applicable to Edmonton, where the modified surface layer was more likely to produce a stratified pollutant distribution.

The widely referenced work on mixing heights in Canada by Portelli (1977) compared vertical mixing conditions at locations across Canada. Portelli showed that a trough of low mixing heights just east of the Rockies and including most of Alberta is characteristic of winter conditions, and is associated with the frequency of chinook inversions. According to Portelli, low mixing heights and chinook inversions, coupled with a particularly high frequency of persistent light surface winds in the area during winter, contribute significantly to high pollution potential in Alberta.

3.3.4 Ventilation

Ventilation is defined as the ability of the atmosphere to disperse pollutants within the boundary layer. Light winds in conjunction with low mixing heights produce conditions of poor ventilation and weak vertical mixing of pollutants. The maximum ventilation coefficient, computed as the product of the maximum mixing height and the mean wind speed through the mixed layer, is used as an index of air pollution potential in urban areas (Portelli 1977).

Analysis of vertical wind and temperature profiles in Edmonton and Calgary (Hage and Longley 1970) has shown that periods of light winds of several days' duration may create conditions of poor ventilation and high pollution potential in both cities in winter. In addition, Hage and Longley have suggested that there exists a potential for stratification of pollutants in the lowest few hundred feet over Edmonton on clear calm nights in summer, and at all hours of light winds in winter.

Angle (1974) also noted that, according to the criteria established by the U.S. National Air Pollution Potential Forecast Program and the criteria established in Denver for stagnation and poor ventilation, the average winter dispersion in the Edmonton area is very poor. Thus, the atmosphere cannot tolerate emissions to the same degree as is possible for other cities.

Using the same criteria, Portelli's (1977) analysis of ventilation coefficients for Edmonton confirmed that poor dispersion conditions exist in Edmonton from November to March. Portelli stated that the frequency of chinook inversions and light winds associated with stagnant continental air masses contributes to limited mixing conditions just east of the Rocky Mountains. From a meteorological point of view, Portelli concluded that the region from Edmonton to Inuvik is the area of Canada with the highest air pollution potential during winter. However, Portelli examined ventilation and pollution potential only on a synoptic scale, and did not consider additional limiting factors on mixing conditions such as may be caused by trapping of cold pools of air in valleys, as identified by studies of the North Saskatchewan River Valley (Hage 1979; Hage and Hopps 1982b).

3.3.5 Frequency and Influence of Chinooks

The chinook is considered to be the most important hydrometeorological phenomenon that occurs in Alberta in winter time. Although the significance of the chinook phenomenon to air pollution potential has long been recognized by researchers (Ashwell 1968), various studies in Calgary have reported conflicting conclusions regarding the effects of chinooks on air quality in that city. It would appear that the controversy stems, at least in part, from the lack of a generally accepted quantitative definition of atmospheric conditions that constitute a chinook. While some studies have used classification criteria based upon surface temperature, wind speed, and wind direction to define a chinook, other studies have noted that adverse pollution dispersion potential exists on days when surface temperatures do not rise and at the same time an "upper-level" chinook traps pollutants under an inversion.

Longley (1967) examined the frequency of chinooks in Alberta by defining a day with a chinook as any day during December, January, or February, on which the maximum surface temperature reaches 40°F (4°C). Brinkmann and Ashwell (1968) used a line of

recording stations between Calgary and the front ranges of the Rocky Mountains to observe changes in temperature, humidity, and, in some cases, wind speed and direction for case studies of chinooks. Using a scheme based on temperature differences during a running six-hour series to define a chinook, Brinkmann and Ashwell noted that normal diurnal temperature changes sometimes grossly affected their results, and thereby made it difficult to clearly define a chinook.

Angle (1974) provides a summary of work published prior to 1974 on chinooks in Alberta in which he describes the phenomenon as follows:

> The chinook is associated with a series of standing waves that form in the lee of a mountain range under certain atmospheric conditions. Wave crests and troughs will lie nearly parallel to the mountain range. The amplitude of the wave system depends mainly on the strength of the westerly winds in the lower troposphere. With light winds the amplitude will be small and the chinook current may not reach the ground, particularly if the wavelenth is small. The warm air will then lie above a shallow layer of colder air at the surface, producing a strong inversion under which pollutants are trapped. The prominent hills to the west and north of Calgary further inhibit the surfacing of the warm air, thereby contributing to the formation of the chinook inversion over the city.
> (Angle 1974:4)

More intensive studies of chinooks by Lester (1975, 1976, 1978) provided a conceptual model of the chinook that included a synoptic scale advective component coupled with a dynamic, gravity wave component on the mesoscale. Favourable conditions for chinooks were identified as a stable, southwesterly flow aloft coupled with an upwind ridge and downwind trough in the surface pressure pattern. In the classical case, the development stages include:

1. a pre-chinook stage, with cold arctic air at the surface;
2. chinook onset, characterized by falling surface pressures and the retreat of cold air to the east, frequently accompanied by gusty surface winds; and

3. chinook cessation, characterized by the southward injection of cold air along the mountains.

Based on the conceptual model, Lester defined a chinook event at Calgary as "a period when the daily maximum temperature is above the long term mean maximum for the month, the wind direction is SSW to WNW and the windspeed is 16 km/h (4.5 m/s) or greater" (Lester 1976:2).

However, Lester (1975) noted that there is often a large variability in chinook phenomenon that departs from the conceptual model and that often causes localized but abrupt onsets and cessations of the chinook. The removal of cold air from the lee of the mountains in the days prior to the chinook onset at the surface is often an irregular process. At times, general warming may be accompanied by only moderate winds at the surface.

Adhering to Lester's strict, quantitative definition of a chinook as quoted, Western Research and Development Ltd. (1977a) examined the relationship between hourly air quality data in Calgary and chinooks. It was concluded that poor air quality episodes typically occurred in the evening with light to moderate southwesterly geostrophic winds, and that chinooks per se were not a factor in causing poor air quality. There was some indication, however, that poor air quality was associated with calm periods preceding and following a chinook. The lack of correlation between poor air quality and chinooks is understandable since, by definition, chinooks were identified as having surface wind speeds greater or equal to 16 km/h (4.5 m/s), and thereby associated with good ventilation conditions.

In direct contrast to Western Research's study, Leggat (1978) and Nkemdirim and Leggat (1978) reported increased urban heat island intensity and decreasing air quality associated with chinooks. Leggat (1978) defined a chinook-day as a day having a maximum surface temperature above 4°C and a chinook arch (a wave cloud formation) over the western sky. Nkemdirim and Leggat (1978),

on the other hand, defined chinook weather as that which follows the appearance of a chinook arch, a sharp drop in relative humidity, and winds with a strong westerly component. A second type of chinook weather was identified as an upper air chinook in which warmer temperatures were trapped aloft. By this definition, some non-chinook events may have been erroneously classfied as chinooks, although the authors felt that their inclusion had only a marginal effect on results.

Nkemdirim and Leggat (1978) concluded that the following factors contribute to poorer air quality in Calgary during chinook weather:

1. Since chinook episodes are usually preceded by southeasterly winds, strong advection of pollutants to the downtown core from industrial sources southeast of the city occurs in pre-chinook conditions.
2. The mixing depth during chinook weather is reduced to a well defined boundary layer of about 330 m thickness, in which pollutants are concentrated.
3. Although chinook weather is accompanied by higher wind speeds on average, steeply rising hills to the west and north of the downtown core effectively reduce total ventilation through the boundary layer during chinook weather.

These findings appear to be in close agreement with results of other studies. Angle (1974) estimated that Calgary experiences a chinook on about one day in four during winter, and that the most serious pollution potential exists under "pre-chinook" or "upper-level chinook" conditions when a strong chinook inversion is present and there is poor surface ventilation. Moreover, Mathews and Hicks (c. 1978) showed that it was during calm periods of chinook-associated ground-level warming that the most severe pollution episodes occurred in Calgary during the 1976-77 period. Using acoustic sounder data, Hicks and Mathews (1979) identified the

presence of an urban boundary layer, 200 to 500 m thick, linked with chinook winds that may persist for many hours after surface related chinook conditions have ended. Mathai, Harrison, and Mathews (1980) concluded that chinooks are accompanied by high concentrations of particles, which create poor visibility and possibly pose a health hazard to some individuals.

However, Nkemdirim and Leggat (1978) have noted that other investigators have disputed the exact relationship between the effect of chinooks on urban heat islands and atmospheric pollution. This controversy was also referred to by Harrison and Mathai (1981a) who felt that a thorough understanding of the effects of chinooks on urban air quality requires further investigation.

3.4 AIR QUALITY MODELLING IN ALBERTA

Urban air pollution modelling in Alberta has been essentially restricted to the application of dispersion modelling techniques to both Calgary and Edmonton. Initial studies were conducted using the simple box modelling techniques. Subsequent studies considered the use of numerical modelling techniques applied to carbon monoxide diffusion from roadways, primarily within the North Saskatchewan River Valley. Chemical transformation modelling has been restricted to a single study of homogeneous gas phase conversion of sulphur dioxide to sulphuric acid.

3.4.1 Dispersion Modelling

Initial attempts to develop air quality models for the cities of Edmonton and Calgary were conducted by Western Research and Development Ltd. (1976a, 1976b; Leahey 1975). The purpose of the research was to apply a simple advective model (initially developed by Summers 1965) in order to predict ground-level concentrations of NO_x, CO, and water vapour as a function of meteorological variables. The model was based on a non-diffusive, air-column trajectory approach that relied on the principle of mass

conservation. It was also assumed that the horizontal wind velocity was constant in time and space, and that, within the vertical mixing layer, thermal turbulence results in a uniform distribution of pollutants.

The modelling results showed that, for both cities, the highest concentrations of NO_x, CO, and excess moisture content would be expected to occur downwind of the city, and that the concentrations of NO_x were more likely to be of concern than the concentrations of CO. The overall correlation coefficients between predicted and observed concentrations in Calgary were 0.63 for NO_x and 0.60 for CO. The comparable correlation coefficient achieved in Edmonton was 0.6 for both NO_x and CO. The authors of the studies reported overall average errors within a factor of one-half of observed values. However, these modelling studies did not consider the potential influence of the river valleys in both cities on trapping of pollutants within the valleys, nor did they consider effects on dispersion due to the urban heat island that had been observed for both cities by other studies (e.g., Hage 1972 reported that sensible heat release within the city was significant).

Further work conducted by Western Research and Development Ltd. (1977b) considered the assimilative capacity of the atmosphere over Edmonton for urban area emissions under various meteorological conditions. The study used the air column trajectory model (discussed above) to estimate CO and NO_x concentrations for stable atmospheric conditions over the winters of 1974-75 and 1975-76. The study also utilized a simple dispersion model for chemically reactive pollutants developed by Hanna (1973) to estimate concentrations during neutral and unstable conditions. The results indicated that the poorest urban air quality occurs under stable conditions. On the other hand, the influence of Edmonton's industrial source emissions (Strathcona) on east Edmonton was reported to be relatively small under neutral or unstable conditions. Evaluation of expected present and future maximum

ground level concentrations of CO and NO_x indicated that these concentrations should be generally within the desirable limits defined by the air quality standards. It was anticipated that the installment of vehicle emission control devices in 1976 would result in a substantial reduction of ground-level CO concentrations attributable to urban emissions over the following decade (i.e., 1976 to 1986). Ground-level concentrations of NO_x were expected to remain essentially the same.

A simple box model approach was used by Hwang (1978) to examine the problem of elevated levels of CO within the North Saskatchewan River Valley that form as a result of inversion trapping, stagnation, impingement, downwash, and recirculation of air in valley wind systems. Hwang used a two-layer numerical box model (similar to one described by Lettau 1970), in which the lower box was used to represent conditions within the river valley, while the upper box was representative of the city atmosphere above the valley. Model assumptions included conservation of mass, in which the horizontal transport of pollutants was dominated by the along-valley wind component.

Although the model required gross spatial averaging and numerous approximations because of the severe limitations of the experimental data, the objectives of the study were fairly conservative and justified a simple approach. The model predicted hourly carbon monoxide concentrations that were comparable in magnitude to the observed concentrations derived from traverse measurements. However, the pronounced evening maximum concentrations predicted by the model were not confirmed experimentally, although late evening maxima were present at low elevations on both sides of the valley. Evidently, the complexity of the variations in temperature, wind, turbulence, and pollutant transmission within the valley were beyond the capabilities of this simplified approach.

Further work on the problem of pollutant transport within an urban river valley was conducted by Rudolph (1980), who used a

numerical particle-in-cell approach to estimate the two-dimensional diffusion of CO within the North Saskatchewan River Valley under clear sky, light wind, and inversion conditions. The model correctly predicted the trend to decreasing concentrations with increasing slope wind speed and decreasing source strength. Within the limits of the study (i.e., small, closed valley system with a single, along-valley line source), it was determined that the ground-level concentrations downslope from the source were apparently controlled by a combination of advection and initial source diffusion. Atmospheric diffusion after initial plume growth was of secondary importance, suggesting the need for a more accurate parametrization of vehicle emission sources.

Hage and Hopps (1981, 1982a) also reported results from the application of a numerical modelling approach for surface concentrations of CO from low-level area sources in Edmonton. The model was applied to periods of stable atmospheric conditions and stagnant air flow. The model results were compared with observed hourly CO concentrations and yielded a correlation coefficient of 0.79 $\pm$ 0.01 (62 percent of total variance) with a standard error of 1.9 $\pm$ 0.01 ppm. It is important to note that the Hage and Hopps numerical modelling approach is most suitable for the simulation of non-reactive gases from low-level sources and therefore is not suitable for overall urban airshed management.

3.4.2 Chemical Transformation Modelling

Bottenheim and Strausz (1978) have conducted the only study of photochemical transformation of pollutants in Alberta that is applicable to urban environments. Their model was adapted from the work of Demerjian et al. (1974), with some improvements related to the definition of reactions and reaction rates. The emphasis in their study was placed on analysing the influence of large temperature and solar radiation differences between winter and summer in northern latitudes on the homogeneous gas phase conversion of SO_2 to sulphuric acid.

The results showed that, in contrast to studies conducted in lower latitudes (e.g., Los Angeles), seasonal temperature variations in more northerly latitudes exert only a relatively small influence on chemical transformation of polluted atmospheres. On the other hand, the difference in average solar variation during different seasons could substantially alter chemical reactions. Therefore, the potential for photochemical smog is limited in winter by low levels of solar radiation, while the formation of high oxidant levels can be expected to occur during the summer as a result of chemical reactions between NO_x and hydrocarbons when these species are emitted in large quantities by industry and/or automobile traffic. However, significant potential for photochemical pollution in Alberta would also exist during spring or autumn when the solar altitude is still fairly high and the mixing height of the atmosphere is relatively low.

Bottenheim and Strausz (1978) also concluded that atmospheric chemical processes in Alberta are probably very different during the summer and winter. While homogeneous gas phase chemistry in summer results in potentially high levels of pollutants of photochemical origin, it was suggested that liquid phase and heterogeneous chemistry should be more important in determining atmospheric chemical processes during the winter. Since very little work has been done on seasonal influences on atmospheric chemical processes in Alberta, the authors' conclusions have not been confirmed.

While the results of this study are useful in evaluating some aspects of chemical processes in polluted urban atmospheres, the model does not consider the effects of atmospheric turbulence on dispersion. Therefore, while the model is a useful research tool, it too is not suitable for air quality management purposes. Bottenheim and Strausz recognized this deficiency and recommended that future work consider the adaptation to Alberta conditions of models currently under development elsewhere that would combine both chemical and physical atmospheric processes and could be modified to assist in urban airshed planning in Alberta.

3.5 STUDIES OF EFFECTS/CONSEQUENCES OF AIR POLLUTANTS IN ALBERTA

3.5.1 Health Effects

Only two studies of adverse health effects in relation to air pollution in urban centres in Alberta were available for this review. One study examined the effects on health of exposure to CO in individuals during the course of normal activities, while the second study adopted a methodology of sampling a population in households in order to determine possible health effects in relation to benzo(a)pyrene in suspended particulate matter. Results of the two studies are strikingly different, and reflect the difficulties inherent in determining relationships between health effects and air pollutants.

The studies conducted by Smith et al. (1974) and Smith (1975) have already been discussed in subsection 3.2.3.3 in relation to monitoring of CO in Calgary. Smith et al. (1974) examined the extent to which individuals on the streets in downtown Calgary were exposed to CO by making hourly measurements of CO levels at street level in the central business district. Based upon measured CO exposures during an 8-h workday and end-of-workday carboxyhemoglobin levels (COH_6), Smith (1975) concluded that the worst area of CO pollution in Calgary was the downtown area.

> Levels of CO at street level in the CBD (Calgary business district) exceeded the Alberta eight-hour standard of 5 ppm for 23 out of 24 test days. Peak CO levels measured at street level, inside buses and particularly automobiles, inside parkade ticket booths and auto repair areas, and on the ground floors of unsealed buildings in downtown Calgary were sufficiently elevated to be a health hazard to older persons with latent heart disease.

While the results showed that the CO levels in Calgary did not rank with the worst areas for CO pollution in North America (e.g., Los Angeles, Chicago, and probably Denver), on occasion, public exposure to CO in downtown areas of Calgary can rise above those in many other urban areas. Peak hourly levels of CO in late

afternoon in winter frequently rose to 35 to 40 ppm for up to 2-h periods, and a maximum hourly level of 72 ppm was observed.

The second study of adverse health effects in Alberta was conducted by Greenhill et al. (1975) to examine the relationship between respiratory function and levels of suspended particulates. Populations in Edmonton, Calgary, Lethbridge, Medicine Hat, Red Deer, Grande Prairie, Camrose, St. Albert, and Hinton were sampled at home by means of a questionnaire consisting of three parts:

1. public attitudes and preception of air pollution;
2. short questionnaire on respiratory health; and
3. information on personal background.

Portable spirometric equipment was used by the interviewers to conduct a short series of respiratory function tests on each respondent. Air samples for a 24-hour period were obtained on the same randomly chosen day each week, but not necessarily corresponding to the days of household interviews. The suspended particulate matter from the high volume air samplers was analysed for benzo(a)pyrene. The limiting assumptions of the study were as follows:

1. that the pollution levels recorded on a randomly chosen day each week were representative of the pollution levels to which the local population was exposed;
2. that everyone within a one-mile radius of each high volume sampler was exposed to the same level of air pollution as that recorded by the sampler; and
3. that the sample of the population successfully interviewed was representative of the population from which it was drawn.

Greenhill et al. (1975) concluded that "air pollution" in urban areas of Alberta could not be shown to be a hazard to health. Respiratory function, which was found to be subnormal for about one-quarter of the population, could not be correlated to levels of

air pollution (as defined by benzo(a)pyrene in suspended particulates) in the areas surveyed.

The approach taken by Greenhill et al. (1975) was purely statistical, and did not examine direct cause-effect relationships in the manner of Smith (1975) and Smith et al. (1974). Furthermore, the limiting assumptions raise questions about the representativeness of the pollution and population data with respect to exposure levels within the population.

Studies in other urban centres in Canada (Silverman et al. 1982) have shown that there is no fixed relationship between pollutant concentrations measured at fixed (neighbourhood) monitoring stations and human exposure levels in households, and that, therefore, it is inappropriate to attempt to relate human health effects to pollutant levels recorded at such stations.

"It is now generally accepted that the best estimate of human exposure to air pollution is obtained by personal monitoring, in spite of its inherent limitations of practicability and cost." (Silverman et al. 1982:233)

A more suitable study would have examined respiratory dysfunction of specific individuals in relation to exposure levels in the course of various activities, and not just at households.

3.5.2 Nuisance Effects

Surveys of public perception of air quality indicate that, on the whole, Albertans are much more likely to associate pollution with odour or with effects on the cleanliness of their homes, their cars, or their bodies, than in terms of direct effects on their health (Greenhill et al. 1975). Public assessments of the meaning of air pollution tend to rank bad odours as the primary aspect of air pollution, with haze or fog, and dust in the air as ranking second and third in most locations. Frequent eye or nose irritations are generally ranked fourth and fifth in such surveys, although in some specific locations they may outrank dust in the air

(Stanley Associates Engineering Ltd. 1973). Perception of the seriousness of air pollution problems varies from area to area. Specifically, bad odours associated with transportation exhaust, meat processing plants, chemical plants, refineries, and sewage treatment facilities are the major cause of public complaints regarding air quality in their neighbourhoods. (Stanley Associates Engineering Ltd. 1973 and Strong, Lamb and Nelson Ltd. 1973)

3.5.3 Inadvertent Climate Modification

Park (1981) investigated the influence of very low air temperatures on the formation of ice fog and precipitation (snow) from the emissions of the Strathcona County industrial area near Edmonton. As noted by Park, very little work has been done on this topic despite the possible implication for industrial development in Alberta. Since only the abstract and introduction to the study were provided to ESL for this review, a review of the work was not possible. However, it seems that the topic should be further researched.

3.5.4 Public Concern and the Index of Quality of Air System

Among the urban population in Alberta, the general perception that an air pollution problem exists has been identified repeatedly in a number of public surveys. For example, Stanley Associates Engineering Ltd. (1973) concluded that the Edmonton area had significant occurrences of odour that were objectionable to many people. Although this was not perceived to be an extremely serious problem, there was a definite public "concern and awareness of the problem to the extent that most residents feel that stronger measures should be taken to control pollution". A study of odours by Strong, Lamb and Nelson (1973) produced similar results for Calgary.

Greenhill et al. (1975) found that residents of Hinton, and those of downtown and industrial areas of Edmonton and Calgary, perceived air pollution to be a serious problem. Fully 88.5 percent of respondents in the study felt that air pollution could be reduced, and respondents in general felt that city officials, provincial government agencies, and industry were not doing enough about air pollution. Although respondents tended to relate air pollution to tangible effects on the cleanliness of their homes, their cars and themselves, "Ninety-nine percent of respondents felt that air pollution was harmful to a person's health, and 25 percent felt that their own health had been affected". Perception of the effects on health was directly related to air pollution factors present in the working environment.

More recently, Krahn (1982, 1983) reported on the public perception of environmental issues in Edmonton, and his conclusions tended to re-confirm the findings of Stanley Associates (1973) and Greenhill et al. (1975) "There was a strong consensus that the government should be doing something about problems of air pollution, that strict enforcement of air quality standards was necessary, and that this enforcement should include prosecution of polluting industries." (Krahn, 1983:23)

Although the issue of air quality in Edmonton shifted from fourth highest to first highest in importance between 1981 and 1982, this sudden shift need not be interpreted as indicative of a sudden decrease in air quality in Edmonton. Studies elsewhere (see Section 4.4.4) have shown that public awareness of air quality is highly correlated with media coverage. It is possible, though this was never investigated by Krahn, that the sudden increase in public concern and awareness of air quality as a primary issue was associated with a specific event, or events, that received attention from the media. Stokes (1983) reported that such a shift in increased concern did indeed follow the Lodgepole blowout incident in

1983. Nevertheless, the fact remains that over the past decade the public, specifically in Edmonton and Calgary, has consistently perceived air pollution as a problem that is not being treated with sufficient attention by responsible agencies. Since the Lodgepole incident, however, Stokes noted a growing trend in public opinion shifting away from government responsibility alone toward joint government/industry efforts to protect the environment.

The development and introduction of an air quality index in Alberta (Tollefson 1973, Lack 1974) as a means of keeping the public informed about ambient air quality in Edmonton and Calgary was not well received initially by the public or news media (Lack and Schulz 1973). A certain degree of confusion resulted from a lack of understanding about the meaning of index values. The greatest gap in the credibility of the index did not occur when air quality was described as very poor; rather, the public tended to question the description of good or fair conditions when visibility was perceived to be low. A lack of understanding of index values by the public was noted to be a common problem in other urban areas in Canada and the United States (Thom and Ott 1975), and confusion over the significance of values was a frequent reason given by air pollution control agencies for the discontinuance of indices.

A new, short-term index (referred to as the Index of Quality of Air (IQUA)) was developed by the Federal-Provincial Committee on Air Pollution (Environment Canada 1980), and introduced in Alberta by the Pollution Control Division of Alberta Environment in December 1979. The index is based on the National Ambient Air Quality Objectives for Canada and was designed to facilitate intercomparisons of air quality in Canadian cities.

Recent studies of the acceptance and understanding of the current IQUA system were not available, and it would be interesting to know to what extent the IQUA is considered to be a source of information about ambient air quality in Alberta.

4. NATIONAL/INTERNATIONAL LITERATURE REVIEW

The following review of national/international literature is based largely upon publications supplied by Alberta Environment up to February 1984. The review is not exhaustive, and it is probable that many important publications are missing. However, it is felt that the review provides a reasonable assessment of the current status of research on air pollution in general.

4.1 ATMOSPHERIC PROCESSES IN URBAN AIR QUALITY

4.1.1 Meteorological Factors Affecting Air Pollution

The importance of meteorological factors in the transport, dispersion, removal, and transformation of air pollutants has long been recognized, and the literature on the subject is relatively voluminous. However, because the transport and dispersion mechanisms are relatively easier to study, these aspects of pollutant transmission have received far more attention than those of transformation and removal. Therefore, the horizontal and vertical definitions of temperature, wind, and turbulence fields are generally considered to be of primary importance to air quality studies, while the measurement of solar radiation, humidity, and precipitation is often considered to be of only secondary importance.

Szepesi (1982) has provided an estimate of the relative importance of various meteorological factors to pollution processes with respect to scale (Table 3).

Table 3. Relative importance of meteorological factors to pollution processes.[a]

Priorities[b]	PROCESS SCALES				
	Local 0 to 10 km	Urban 0 to 30 km	Regional 30 to 200 km	Continental 200 to 3000 km	Global > 3000 km
1	D	P	P	T	Kw
2	Hp	U	Z	Kw	K
3	U	Kd	Kw	Z	T
4	σ	Z	Kd	U	-
5	Z	K	K	Kd	-
6	Kd	Kw	U	K	Kd
7	Kw	σ	Hp	-	-
8	K	Ha	σ	-	U

[a] After Szepesi 1982.

[b] Priorities of the main factors of transmission for different-scale pollution processes are given in order of highest (1) to lowest (8) priority.

D = wind direction
U = wind speed
P = wind pattern (at the height of the plume)
T = trajectory (925 mbar)
Kd = dry deposition (wind speed, surface roughness)
Kw = wet deposition (duration and intensity of precipitation)
K = transformation (solar radiation, temperature, relative humidity)
σ = dispersion
Z = mixing height
H = effective height of point area sources

As the scales vary, the relative importance of the factors of transmission changes as follows (continental and global scales not relevant to this review):

1. While wind direction is of primary importance on a local scale, understanding the overall wind pattern is most important on urban and regional scales.
2. Effective height of emission is very significant on a local scale, but generally less important on urban and regional scales. However, the effective height of point and area source emissions becomes very important in circumstances where the urban mixing height is of comparable magnitude to the effective height of emission.
3. Wind speed has high priority on both local and urban scales, and is relatively important for determining dry deposition rates on a regional scale.
4. The effects of turbulent dispersion must be taken into account on local, urban, and regional scales, but the relative importance of turbulence decreases with increasing scale.
5. Mixing heights, which are generally less important for local studies, become increasingly important in evaluating the growth of the urban plume. Moreover, mixing heights are extremely important if they are of the same magnitude as plume heights and effective height of emission.
6. Removal mechanisms of wet and dry deposition and transformation mechanisms assume increasing importance in urban scale studies.

In 1975, the World Meteorological Organization (WMO) distributed a questionnaire in an attempt to establish the status of knowledge about urban atmospheres. Van Gysegem (1978) reviewed the replies along with then recently published literature on urban measurements of temperature, wind, radiation, and rainfall using surface monitoring, low-level measurement by towers, radiosondes, constant volume balloons, and remote sensing techniques. The review indicated that, although a large number of cities in the world have been subjected to extensive meteorological studies, most studies have dealt with the spatial variation of the urban heat island with primary emphasis placed on near-surface temperature measurements. Only a limited number of studies have attempted to analyse the spatial and temporal changes in wind and temperature profiles, radiation, and precipitation. Even fewer studies have attempted to detemine changes in the turbulent structure of the urban boundary layer and energy balance.

Given the many meteorological factors that affect pollution transmission, it is generally true that the desired meteorological data for air pollution studies are never available to the extent required for a thorough understanding of the atmospheric situation (MacCready 1978). Typically, researchers must make compromises between data that can be obtained in a practical (i.e., economical) manner, and the requirements for describing the atmosphere in sufficient detail for specific purposes. If an air quality model is being employed, the sophistication of the model will determine the detail with which the atmosphere needs to be measured and described. A standard diffusion model uses only one representative mean wind speed and direction for plume transport, one source strength, one mixing height, and one lapse rate. On the other hand, if the region of interest covers complex terrain or rapidly changing meteorological conditions, or if pollutant concentrations over a

time period are required, then both the diffusion model and the data base need to be more complete. Complex photochemical modelling may require the generation of three-dimensional, time-varying fields of temperature, water vapour, and winds.

According to Van Gysegem, the following aspects of urban atmospheric conditions are insufficiently understood and require further research:

1. the coupling between the micro-scale street level environment and the meso-scale urban boundary layer;
2. radiation and energy balances of the "urban surface" for various urban surfaces;
3. classification of the different land-use areas (commercial, residential, suburban, etc.) with a proper quantification, if possible, by physical parameters (e.g., surface roughness, albedo);
4. quantification of heat, moisture, and momentum exchanges in open spaces, at rooftop level, and in the urban boundary layer;
5. spatial and temporal variation of humidity;
6. vertical structure of the meteorological parameters in the urban boundary layer; and
7. proper averaging time for measurement of meteorological parameters.

Van Gysegem also notes that the high degree of turbulence, together with the presence of various obstructions in urban areas, affects the various methods of making meteorological observations. Therefore, further research is necessary on the following topics:

1. experimental evidence of coupling errors due to exposure of the sensors;
2. the representativeness of data over specific land-use areas;

3. errors that result from sensor response in the turbulent urban environment; and
4. development of appropriate and low cost measuring and data processing systems, such as eddy correlation methods, low level radiosonde systems, wind tracking systems for kytoons, and remote sensing techniques.

Faced with the complexity of urban atmospheres and the dearth of meteorological observations at the urban scale, many researchers have restricted their work to local-scale studies. For example, Anthes and Warner (1978) state that much of the air quality modelling to date has been conducted at the microscale (i.e., scale of atmospheric motion less than 2.5 km). At this scale, continuous monitoring with instrumented towers is sufficient to provide a data base for local air quality studies. However, at larger scales, mesoscale circulations may dominate the transmission of pollutants, and may require extensive meteorological data for air quality modelling. Examples of such situations include channelling effects of valleys in stable conditions, mountain-valley (katabatic) breezes, lake breezes, sea breezes, and small-scale variations in precipitation induced by terrain. In such situations, it may be preferable to use meteorological models to simulate atmospheric conditions rather than conducting an extensive program of meteorological monitoring. Anthes and Warner list some of the applications of meteorological models on various scales for air pollution studies (Table 4).

Table 4. Applications of meteorological mesoscale models.[a]

Scales (km)	Application
2.5 to 25	power plant siting
	highway siting
	industrial plant siting
	windmill siting
	urban heat island
	lake breeze
	mountain-valley breeze
25 to 250	sea breeze
	short-range weather prediction
	medium-range pollution transport/removal
250 to 2500	subsynoptic weather prediction
	long-range pollution transport/removal
All scales	mesoscale climatology
	severe weather
	trajectory calculations
	dynamics/energetics of mesoscale systems

[a]After Anthes and Warner 1978.

Anthes and Warner (1978) examined the role of two specific mesoscale meteorological models in solving a variety of air pollution problems and concluded that, although such models are relatively expensive, their versatility make them applicable to problems that cannot be modelled adequately by simpler methods.

Maddukuri et al. (1978) also examined the problem of computing wind, temperature, and turbulence parameters for use in urban air quality models, and arrived at a different conclusion. They determined that, depending on the extent of available data, three different, relatively economical approaches could be used to estimate the parameters. Maddukuri et al. examined the problem of incorporating these parameters into existing gradient-transport air quality models. They concluded that, although newer, more complex methods of obtaining reliable temperature and winds are available and can be incorporated into complex air quality models, these approaches are not yet economically practicable.

The problem with all of the existing meteorological models is that the models themselves are based on a limited understanding of physical mechanisms governing the urban atmosphere, and therefore may not provide a realistic estimate of atmospheric parameters. Significant progress toward the understanding of urban meteorological and air pollution phenomena in future will depend on large, experimental programs such as the St. Louis Regional Air Pollution Study (RAPS), which is designed to provide a data base of both meteorological parameters and pollutant concentrations from a dense network of monitoring stations, coupled with extensive supplementary monitoring studies. Such data may be used to validate various types of meteorological and air quality models, which could then be applied in other cities with less stringent input data requirements. Anthes et al. (1978) report that the logistics of future mesoscale experiments of this type will likely be beyond the capabilities of any single government agency, and the success of such experiments will depend on multi-agency co-operation.

4.1.2 Pollutant Transformation in the Atmosphere

Atmospheric emissions from industrial and domestic sources contain numerous gases -- principally sulphur dioxide, carbon monoxide, carbon dioxide, water vapour, and nitrogen oxides -- together with particulate matter containing almost every known element. Lesser quantities of organic gases, mainly hydrocarbons, are also emitted, together with carbon particles (Legge et al. 1980). Under the influence of solar radiation and in the presence of oxygen, these primary species of pollutants are transformed into secondary compounds (e.g., sulphates, nitrates, organic particulates, and oxidants) through a complex series of gas phase reactions or through oxidation in the liquid phase. Legge et al. reported that at least 140 interrelated chemical reactions are believed to occur simultaneously during daylight hours in the polluted atmosphere. In the process, many intermediate compounds are formed that may persist in low concentrations for short periods of time, or that may reach high concentrations and persist for many hours.

Over the past few decades, two particular problems that have attracted attention are the atmospheric transformation of sulphur oxides, which result in sulphurous (i.e., London-type) smogs, and of nitrogen oxides, which are involved in the production of photochemical (i.e., Los Angeles-type) smogs (Oke 1981). In the former case, a liquid phase transformation of sulphur dioxides results in the formation of an acidic mist (H_2SO_4), which subsequently reacts with other substances to form sulphate particles. Photochemical smog, on the other hand, is initiated by the action of solar radiation upon nitrogen oxides and is aided by the presence of hydrocarbons. These primary species of pollutants react in a series of gas phase transformations to produce a range of secondary pollutants, especially oxidants such as ozone, oxygen, nitrogen dioxide, and peroxyacetyl nitrates (PAN). According to Oke, "Photochemical smog is accompanied by a characteristic odour (partially due to

aldehydes and formaldehyde), a brownish haze (due to NO_2 and light scattering by particulates), eye and throat irritation (due to O_3, aldehydes and PAN), and plant damage (due to NO_x, O_3, PAN and ethylene. Odour ranks highest among citizens' complaints in both Edmonton and Calgary. Research on the effects of particulates on visibility and haze has been the topic of several studies in Calgary, and Dr. A. Legge (Kananaski Research Centre, University of Calgary, Alberta; personal communication in interview) suspects damage to vegetation in Edmonton.

Dickson and Quickert (1975) have provided an extensive and detailed review of the literature dealing with the chemistry of photochemical smogs. They report that the reaction rate coefficients and activation energies of many atmospheric processes have been measured, and photochemical systems have been simulated in computer and smog-chamber experiments. It has been well established that gas phase chemical processes in the atmosphere play a major role in converting primary gaseous species to secondary compounds (Isaksen 1982). These studies have shown that chemical transformation in the atmosphere is critically dependent upon the distribution of a few key pollutant species, notably ozone, which control the formation of other secondary compounds. Furthermore, under appropriate conditions of dispersion meteorology, the impact of photochemical smog may extend for hundreds of kilometres downwind (Finlayson and Pitts 1976).

4.1.2.1 Gaseous Transformations. Tropospheric gaseous chemical transformations are driven by solar ultraviolet (UV) and visible radiation that dissociates pollutant molecules. Isaksen (1982) provided a list of dissociation products and energy thresholds for some of the most important species for tropospheric ozone chemistry (Table 5). Of particular importance is the dissociation of ozone

Table 5. Threshold energies for photo dissociation of tropospheric molecules of importance for ozone budget in the troposphere.[a]

Photo Dissociation	Threshold Energy
$O_3 + h\nu \rightarrow O_2 + O(^1D)$	$\lambda < 300$ nm
$O_3 + h\nu \rightarrow O_2 + O(^1D)\ \alpha$	300 nm > λ > 330 nm
$\rightarrow O_2 + O(^3P)\ 1-\alpha$	
$O_3 + h\nu \rightarrow O_2 + O(^3P)$	$\lambda < 330$ nm
$NO_2 + h\nu \rightarrow NO + O$	$\lambda < 415$ nm
$N_2O + h\nu \rightarrow N_2 + O$	$\lambda < 320$ nm
$HNO_2 + h\nu \rightarrow OH + NO$	$\lambda < 395$ nm
$HNO_3 + h\nu \rightarrow OH + NO_2$	$\lambda < 360$ nm
$NO_3 + h\nu \rightarrow NO_2 + O$	$\lambda < 580$ nm
$N_2O_5 + h\nu \rightarrow NO_2 + NO_3$	$\lambda < 380$ nm
$H_2O_2 + h\nu \rightarrow OH + OH$	$\lambda < 380$ nm
$CH_2O + h\nu \rightarrow CHO + H$	$\lambda < 360$ nm
$\rightarrow H_2 + CO$	$\lambda < 360$ nm

[a]Source: Isaken 1982.

in the spectral region 300 nm < λ < 330 nm where ozone absorption is very efficient. The product of dissociation in this spectral region is the main source of atomic oxygen that is sufficiently energetic to dissociate water vapour molecules into hydroxyl radicals (OH). The atmospheric distribution of OH in turn plays a key role in gas phase transformation from primary to secondary pollutant species in the atmosphere.

The basic mechanism for the formation of photochemical air pollution (hydrocarbons - NO_x - UV radiation) has been known since the 1950s. According to Dimitriades (1981), key steps in the complex process are:

1. photolysis of nitrogen dioxide (NO_2), nitrous acid (HNO_2), aldehydes (RCHO), and ozone (O_3), resulting in short-lived free radicals (OH, HO_2, NO, NO_2, and several others);
2. thermal reactions of hydroxyl (OH) and other radicals with organic and inorganic pollutants resulting in additional free radicals and stable products; and
3. secondary thermal reactions resulting in stable gaseous and particulate products.

The key role of reactive, non-methane hydrocarbons (NMHC) in this process has been well documented in the past. However, the quantitative nature of the relationship between NMHC is the subject of ongoing research (Sexton and Westberg 1981). The NMHC - NO_x - O_3 relationship is apparently more complex than was initially postulated. Although smog chamber studies have been conducted to examine this quantitative relationship, it is still not clear to what extent these results approximate events in ambient urban atmospheres.

In a review of major issues and research needs in photochemical air pollution, Dimitriades (1981) states that available evidence on the contribution of natural organics to photochemical pollution is conflicting. Both laboratory and field studies have shown that natural organics are emitted in amounts comparable to, or even greater than, anthropogenic organics and may be more potent O_3 precursors than many of the organics emitted by man-made sources. If true, the effectiveness of reducing O_3 in urban atmospheres by controlling anthropogenic emissions of NMHC would be questionable. This has recently been demonstrated by attempts to lower ambient ozone concentrations in Houston by controlling hydrocarbon emissions. Massive reductions in emissions from vehicular exhausts did not seem to have reduced ozone episodes by any significant amount, and raised serious questions about whether or not future control strategies should emphasize reduction of hydrocarbons, reduction of other precursors such as NO_x, some combination of both, or some other strategy yet to be identified (McKee 1979). If ozone and ozone precursors are transported into the urban area from distant sources, as seems to be the case in Houston, then control of vehicular exhaust will not lead to decreases in ozone episodes. Indeed, Innes (1981) has suggested that, for urban areas, controls on NO may be counter-productive in controlling ozone levels, and a decrease in NO_x emissions could be expected to increase ozone levels. On the other hand, Innes suggests that, for the Los Angeles Basin, a reasonable increase in NO_x emissions together with a similar decrease in hydrocarbon emissions could reduce ozone levels sufficiently to meet air quality standards.

Dimitriades (1981) suggests that the inconsistencies between emission and ambient concentration data could be the result of errors made in the measurement of both natural and anthropogenic emissions, as well as in the measurement of ambient concentrations.

Gordon (1980) has argued the need for a new design in source testing methods, while Dimitriades recommends that, in the absence of reliable emission measurement methods, emission rates of natural organics should be back-calculated from ambient concentrations using dispersion/reaction modelling techniques. Sexton and Westberg (1981) cite the fragmentary nature of information on ambient NMHC concentrations as being one of the factors limiting research on photochemical pollution.[1] While ambient levels of some selected hydrocarbons have been documented, Sexton and Westberg state:

> The required technical expertise and costs of gas chromatographic NMHC analysis have prevented this important research tool from becoming a standard component of most air pollution monitoring networks. (pp. 81-47.3)

In summary, therefore, it would appear that further research into photochemical air pollution will require a greater understanding of the distribution of individual species of reactive hydrocarbons in ambient urban atmospheres and more reliable estimates of natural and anthropogenic emissions. The development of new methods for monitoring emissions, and the more frequent use of gas chromatography in ambient air quality monitoring must be emphasized in future research efforts. Since the concentration levels of many reactive hydrocarbons and key oxidants such as OH are very low, the assessment of the quantitative relationsip between primary hydrocarbons and NO_x - O_3 must rely on a combination of photochemical model calculations and ambient measurements (Dimitriades 1981; Isaksen 1982).

---

1 An understanding of the importance of natural versus anthropogenic hydrocarbons is required to determine their relative contribution in ozone production under physical/chemical conditions in Alberta.

4.1.2.2 Liquid Phase Transformation. Liquid phase chemical transformation involves the absorption of gaseous pollutant species on aerosol particles or in droplets, and is therefore a heterogenous process (Isaksen 1982). It depends in part upon the atmospheric concentrations of gaseous particles, on the amount of aerosols or droplets present, and in most cases upon the acidity of the liquid, which determines the rate of uptake of gases in the liquid.

According to Isaksen, the oxidation processes that convert primary nitrogen species to nitrate in the liquid phase are not well known at present. Although it is thought that chemical reactions oxidizing NO or NO_2 absorbed in droplets are probably less significant than gas phase conversion to HNO_3, no estimates of the efficiency of liquid phase oxidation of NO_x to nitrate (as compared to the efficiency of gas phase oxidation) has so far been performed to verify such an assumption. The importance of liquid phase chemistry of nitrate formation is connected to the uptake of gaseous HNO_3 in droplets, and its dissociation into H^+ and NO_3^- ions. The presence of HNO_3 influences the pH value of liquids and, therefore, may affect the oxidation of sulphur dioxide (SO_2).

As is the case for oxidation of nitrates, the relative importance of liquid phase oxidation and gas phase oxidation of sulphur dioxide to sulphate is difficult to quantify. Some observations appear to indicate that both processes are important, and are dependent upon latitude, season, and degree of pollution.

Middleton et al. (1980) state that the overall rate of urban sulphate aerosol production is a complex function of gas phase photochemical oxidation reactions leading to condensible vapours, the conversion of these vapours into sulphate particles, and the

catalytic and non-catalytic oxidation of SO_2 on wetted aerosol surfaces. According to Blokker (1978), the complicated nature of these competing reaction mechanisms and their dependence on many factors (such as humidity, temperature, sunlight, presence of various compounds, and catalysts) make it extremely difficult to ascertain the contribution of each of these factors to the formation of an aerosol that has been collected, or to predict the mechanism and rate of formation.

Until recently, information on observed sulphate levels tended to consider only the anion composition, while it is now known that important properties of sulphates, such as water solubility, particle size distribution, acidity, and toxicity, depend more upon the molecular composition than on the anion alone. For example, Biggins and Harrison (1979) have found that the atmospheric chemistry of automotive lead is dominated by reactions of lead halides with $(NH_4)_2SO_4$, NH_4HSO_4, and H_2SO_4 in the liquid phase subsequent to the coagulation of primary vehicle exhaust lead halides with ambient sulphates. As a result, entirely new secondary and tertiary sulphate compounds may be formed that may have significant influence on health effects. They report that some studies have shown zinc ammonium sulphate to be a more potent respiratory irritant than either zinc sulphate or ammonium sulphate alone.

Based on theoretical analysis, Middleton et al. (1980) concluded that the proper interpretation of observed sulphate levels in urban aerosols requires the simultaneous measurement of major gaseous species as well as both the size and composition of aerosols. In particular, particle acidity and sulphate concentration with respect to particle size should be measured. Such measurements are not typically part of current air quality monitoring networks. The need for such measurements, however, has recently been recognized by the National Research Council Canada (1982), which

has recommended that standard reference methods for the measurement of the size distribution of atmospheric aerosols be developed. All field programs should include size distribution measurements coincidental with mass and chemical determination. In view of the efficiency of catalytic reactions with metallic ions such as iron, manganese, and lead (Isaksen 1982), the importance of determining concentrations of trace metal species cannot be overemphasized in the design of monitoring programs.

4.1.3 Removal Processes

Removal of atmospheric pollutants is generally classified into three types of processes, namely, wet deposition, dry deposition, and chemical transformations. Wet deposition processes are associated with either in-cloud scavenging (called rainout or snowout) by liquid droplets or ice crystals, or by washout during precipitation. Dry deposition, on the other hand, is subdivided into gravitational settling of larger particles and turbulent diffusion of gases and small particles to near-surface regions. Chemical transformations, discussed in the preceding sub-section, may be thought of as a removal process (as well as a source mechanism) by which some pollutant species are transformed into others in the atmosphere (e.g., SO_2 to sulphate), effectively removing the first (SO_2) even though the element itself (S) is not removed.

According to Whelpdale (1982), the effectiveness of a particular process or combination of processes is dependent upon the following factors:

1. meteorological conditions, such as turbulence intensity, precipitation rate and duration, and solar radiation;

2. properties of the substance, such as physical state, solubility, and reactivity; and
3. characteristics of the surface (wet or dry, nature of vegetative cover, soil pH).

The routine measurement of deposition is easier and more advanced for wet removal than for dry deposition. However, studies have shown that in mid-latitude regions of the northern hemisphere, where most of the work on deposition has been conducted, wet and dry deposition processes are of comparable importance in the removal of substances such as sulphur and nitrogen. Dry deposition is relatively more important in heavily polluted areas near source regions, while wet deposition becomes progressively more important with distance from emissions sources.

Although a great deal of literature has been published on deposition of pollutants in Europe, in eastern Canada, and in the northeastern United States, the literature provided by RMD for this review was singularly lacking in significant publications on removal processes in urban areas. With the exception of the National Research Council Canada (NRCC) study on the effects of aerosols on atmospheric processes (National Research Council Canada 1982), which dealt exclusively with wet removal processes, this review has been restricted in its sources of information to two additional publications obtained by ESL (Whelpdale 1982; Georgii and Prankrath, eds. 1981). While Whelpdale provides a comprehensive overview of processes involved in pollutant deposition in general, his review does not include a discussion of the central research issues still to be resolved (removal mechanisms), nor does Whelpdale consider the particular case of urban pollutant deposition. Similarly, Georgii and Prankrath provide a series of papers presented at a colloquium on pollutant deposition in West Germany. These papers provide descriptions of recent research conducted in Europe (mainly in

Germany), but do not identify comprehensive research needs. The review of aerosols by the NRCC (1982) lists a number of review articles, and the reader is referred to this publication for literature on the topic.

The only comments made here with respect to measurement of removal processes were derived from the NRCC report. Specifically, the report refers to numerous studies dealing with artifact formation during sampling using standard filtration techniques (i.e., high volume sampling with glass fiber filters). Significant errors in sulphate and nitrate ion concentrations due to chemical interactions have been reported, leading to an incomplete understanding of the variations in deposition velocities and fluxes of these aerosols.

Based upon the limited sources of information available to ESL, it was not possible to conduct a more thorough review of the removal processes in urban areas. It would be highly desirable that such a review be conducted in the future in view of the limited amount of work that has been conducted on the subject in Alberta.

4.2 URBAN AIR QUALITY MONITORING

A recurring theme throughout the international literature on air quality research is the question of the accuracy and representativeness of data obtained in monitoring programs. Stern (1976) stated that "as air quality monitoring networks have proliferated over the recent past, so have doubts arisen as to where, when and what to monitor."

As one example, Ader (1981) conducted a review of literature and on-going Environmental Protection Agency (EPA) projects to determine the value of fixed site monitoring networks for estimating the exposure of human populations to carbon monoxide. Ader concluded that fixed site monitors were not accurate indicators of exceedence of EPA's exposure standards. For commuting and urban

pedestrian exposure, fixed site monitors underestimate CO exposure and, therefore, do not accurately assess the extent of CO-related problems in U.S. cities.

Rossano and Thielke (1976) stated that experience with surveillance programs in the U.S. suggests the need for considering the quality rather than the quantity of data. The high cost of analytical instruments that provide quality data as well as operational/organizational requirements of complex surveillance programs may well be beyond the limited resources and time available to many air quality management agencies. Mobile monitoring techniques may be more effective than the establishment of fixed networks. Rossano and Thielke suggest that considerable restraint in network planning and development is warranted, and that the definition of monitoring objectives and basic network design should take precedence over the development of elaborate, but possibly ineffective, surveillance programs.

4.2.1 Definition of Monitoring Objectives

Munn (1978) states that the definition of objectives is the most important factor to be considered in designing a monitoring network. He lists the principal objectives of urban monitoring programs as:

1. continuous surveillance monitoring for regulatory control;
2. exploratory monitoring to determine present conditions and trends;
3. monitoring to provide input data for the development, validation, and operational use of models in:
   a) forecasting of air pollution episodes;
   b) land-use planning scenarios for industry, transportation, and power generation; and
   c) large-scale interdisciplinary airshed management models; and

4. effects-related monitoring to study dose-response relationships (i.e., health effects, vegetation effects, corrosion, and inadvertent climate modification).

Data obtained in order to meet one objective will not necessarily be adequate for other objectives. Ludwig (1978) states that this rather obvious fact is often overlooked:

> A common example of a mismatch between data and application is the development of an air quality control plan for an entire region to eliminate a pollution problem recorded at a station whose data may only be representative of conditions within a few hundred meters of the site. (p. 776)

The converse may also occur, wherein a real pollution problem is missed by the monitored data. Gilmore and Hanna (1976) state that the lack of correlation between ambient levels of CO as measured by monitoring networks and health effects may be due to improper siting of CO instruments, improper interpretation of data, or both.

The stated objective of a monitoring program must determine:

1. specific uses that will be made of the results;
2. the pollutants to be sampled;
3. the number and disposition of sampling sites;
4. the type of sampling to be employed (e.g., average concentrations vs. peak values, or both);
5. length of sampling period (i.e., averaging time);
6. the type of instruments to be employed; and
7. statistical analysis and presentation of results.

Monitoring for regulatory control usually involves relatively short averaging times, in the order of one or two hours up to a 24-h period (Cleary 1974). When high peak values are likely to occur, shorter sampling intervals may be required, which may indicate the need for fast-response instrumentation. Monitoring for epidemiological purposes may require similar sampling time intervals, but requirements for sensor exposure may be quite

different. If long-term exposures are the primary concern, then simpler integrating methods for monitoring may suffice.

Depending upon the stated objective, selection of a sampling site is of the utmost importance. The need for site selection criteria has lead to the concept of classifying stations with respect to spatial representativeness. Ludwig (1978) defined the measurement scales of most importance as follows:

1. Microscale measurements that define concentrations in volumes with dimensions on the order of metres to tens of metres.
2. Middle-scale measurements to generally define concentrations that are typical of areas with dimensions of tens to hundreds of metres. This category can include measurements that define concentrations along streets and roads, so typical areas can be elongated, measuring tens of metres by hundreds of metres or even kilometres.
3. Neighbourhood-scale measurements, which are among the most widely used. They define concentrations within some extended area (having dimensions in the order of kilometres) that has relatively uniform land use.
4. Urban-scale measurements to define the overall city-wide conditions on a scale of tens of kilometres, will usually require more than one site.
5. Regional-scale measurements, which provide a measure of concentrations typical of large, usually rural areas of reasonably homogeneous geography, extending for tens to hundreds of kilometres.

The requirements for spatial representativeness create siting problems even when monitoring objectives are well-defined. For example, Munn (1978) cites numerous authors who have attempted to study the concentration fields of urban CO. Concentrations and concentration gradients of CO vary in both time and space on the

microscale and even on the neighbourhood scale. Munn offers Ott's (1977) system of classifying CO monitoring stations (Table 6). Not all types of stations described in Table 6 will be required in every monitoring program since the selection of a representative station will depend on the monitoring objectives.

However, Ludwig (1978) states that CO is the only major pollutant to which the concept of spatial representativeness can be easily applied. Other pollutants, particularly those which are important to photochemical processes (e.g., NO_x, NMHC, O_3), may require additional modifications to site selection criteria.

Since air quality monitoring networks are already in place in many cities, major modifications in monitoring site location are unlikely in most networks. Economic constraints will limit modifications to small incremental changes. Therefore, Munn suggests that, given a network of stations, some effort should be devoted to examining the types of objectives that the existing network is capable of answering. Furthermore, prior to expansion and/or modification of permanent networks, intensive short-term pilot studies should be undertaken in order to identify suitable monitoring locations.

4.2.2 Parameters to be Monitored

Although the number of potential air pollutants is practically unlimited, only a small number of specific pollutants have been considered important enough to warrant constant monitoring (Rossano and Thielke 1976). Historically, suspended particulate matter and sulphur oxides have been the pollutants most commonly measured in urban areas (Cleary 1974), primarily because they have been associated with increased morbidity. With increasing urbanization and increased use of automobiles, carbon monoxide has become an important health hazard to urban populations. In areas where heavy automobile traffic and strong sunlight produce photochemical pollution, significant eye, nose, and throat irritations along with

Table 6. Recommended criteria for siting monitoring stations.[a]

Station Type	Description
Type A	Downtown pedestrian exposure station. Locate station in the central business district of the urban area on a congested, downtown street surrounded by buildings (i.e., a "canyon" type street) and utilized by many pedestrians.
Type B	Downtown neighbourhood exposure station. Locate station in the central business district of the urban area, but not close to any major streets. Typical locations are parks, malls, or landscaped areas having no traffic.
Type C	Residential population exposure station. Locate station in the midst of a residential or suburban area, but not in the central business district.
Type D	Mesoscale station. Locate station in the urban area at appropriate height to gather meteorological and air quality data at upper elevations. The purpose of this station is not to monitor human exposure, but to gather trend data and meteorological data at various heights. Typical locations are tall buildings and broadcasting towers.
Type E	Non-urban station. Locate station in a remote, non-urban area having no traffic and no industrial activity. The purpose of this station is to monitor for trend analyses, for nondegradation assessments, and for large-scale geographical surveys. The location or height must not be changed during the period over which the trend is examined.
Type F	Specialized source survey station. Locate station very near a particular air pollution source under scrutiny. The purpose of the station is to determine the impact on air quality, at specified locations, of a particular emission source of interest.

[a]Source: Ott 1977.

changes in pulmonary function and asthma have been noted. Therefore, where photochemical pollution is likely, the parameters associated with photochemical transformations are also monitored. These include primary pollutants such as hydrocarbons and oxides of nitrogen as well as many secondary pollutants such as ozone, various aldehydes and nitrated olefinic hydrocarbons, peroxyacyl-nitrates, and other compounds. In the vicinity of certain industries, monitoring of specific pollutants might include lead, cadmium, mercury, beryllium, asbestos, fluorides, arsenic, nickel, manganese, and polycyclic aromatic hydrocarbons.

There are no generally accepted standards for pollutant monitoring in urban areas. Most programs are designed to monitor only those pollutants for which there are established ambient air quality standards. In Canada, standards are available for SO_2, NO_2, O_3, CO, and suspended particulates. The World Health Organization (WHO) has been unable to formulate a set of standards for short-term goals in urban ambient air quality for a variety of reasons (World Health Organization 1972). However, the WMO (Junge 1974) has provided a set of guidelines for monitoring pollutants that influence either atmospheric processes or the biosphere at the regional and global scales.

Ludwig et al. (1976) identify the specific requirements for monitoring atmospheric constituents associated with photochemical pollution (Table 7). The classification of monitoring sites is similar to the concepts of representative scales for CO developed by Ott (1977).

4.2.3 Criteria for Siting Monitoring Stations

There does not appear to be a firm set of criteria for determining the required number and spatial distribution of monitoring sites in an urban network. The WMO siting criteria for regional and baseline stations (Junge 1974) are not applicable

Table 7. Monitoring site types for photochemical pollutants.[a]

General Type Site	Characteristic	Scale to be Represented	Photochemical Pollutants to Which Site is Applicable	Other Important Factors
Neighbourhood	Source-oriented	Smaller end of the neighbourhood scale, 1 to 2 km	NO_2, NMHC[b], NO	Areas where measurements will identify contributions of specific sources
Neighbourhood	General	Neighbourhood	NO_2, NMHC, O_x, NO	Areas where measurements will be dominated by single sources are to be avoided
Urban	Important reactant area	Urban/regional, tens of kilometres	NO, NMHC, NO_2	Areas where reactants can be expected to contribute importantly to photochemical air quality in region
Regional	Important product area	Regional, hundreds of kilometres	O_x, NO_2, sulphates	Areas where important photochemical pollutant products are expected to occur
Urban/regional	General	Urban/regional	NO, NO_2, NMHC, O_x, sulphates	Areas where measurements are representative of whole region without regard to importance in larger scale photochemical processes
Traffic effects	Street canyon or traffic corridor	Middle, on the scale of streets	NO, NO_2, O_x	Must be a large traffic source of NO nearby

[a]After Ludwig et al. 1976.
[b]Non-methane hydrocarbons.

because of the necessity to monitor at various scales within the urban structure (Munn 1978).

The variety of monitoring objectives, the averaging times associated with the air quality standards, the physical environments in which sites could be located, and the spatial scales of representativeness all combine to make the selection of monitoring sites a rather complex procedure (Bell and Anderson 1977).

There are three general ways to estimate the concentration fields and variabilities of pollutants in order to aid in the development of optimum sampling networks. One method is to use mathematical (i.e., dynamic or statistical) models for locating sites to monitor major point or line sources of emissions. Techniques have also been developed for determining sampling site locations at the urban scale (i.e., Vukovich c. 1976), as in the case for the Regional Air Pollution Study in St. Louis. Munn states that the urban modelling techniques may be especially useful in complex terrain and for multiple source emissions, but their capabilities are insufficiently accurate for establishing neighbourhood scale monitoring locations.

A second approach that may be particularly useful for site selection at the microscale in canyon streets is the use of wind-tunnel or fluid-simulation scale models. The principal disadvantages of this technique are that it is costly and time-consuming and, in Munn's opinion, is of little value in the operational task of selecting monitoring stations.

Finally, a third approach, probably the one most commonly used, is to have a meteorologist make a subjective appraisal of the effects of local emission sources, as well as local structural and topographic effects on probable pollutant concentrations. Depending upon the resources of the monitoring agency, the final site selection is based upon a trade-off between stated monitoring objectives and available financial resources.

In the ideal situation, a separate appraisal of monitoring sites should be made for each pollutant. The Environmental Protection Agency in the U.S. has issued a guideline for the minimum number of stations used in regulatory monitoring for compliance with ambient air quality standards (Environmental Protection Agency 1975). The requirements (Table 8) are based primarily upon population size in an urban area. For monitoring around major point sources, the EPA guidelines require a minimum of three stations (Table 9).

In Canada, the Environmental Protection Service has issued a set of site selection criteria (Environmental Protection Service 1976 and 1977), which were adapted from the EPA guidelines. The general rules for establishing NAPS network stations are presented in Table 10. There are two types of stations specified for urban areas. Class I stations are fundamentally population oriented, and are used for monitoring air quality trends with respect to national air quality objectives. Stations located in downtown areas and along commercial developments with heavy vehicular traffic area used or monitoring pollutants on a middle scale defined as typically ranging from about 100 m to 0.5 km (up to several city blocks). Class I stations in residential areas are used for measuring concentrations of pollutants on a neighbourhood scale within an extended area of the city (0.5 to 4.0 kilometers), having relatively uniform land use. Class II stations, on the other hand, are used for monitoring specific urban pollution problems due to industry, automobiles, or power generation. These stations are pollutant oriented, and only pollutants that are considered to be significant to a particular air quality problem are monitored. Since it is generally desirable to have monitoring data representative of population exposure, the majority of Class II stations should satisfy neighbourhood scale siting requirements.

Table 8. Regulatory requirements for minimum number of monitoring sites.[a]

Classification of Region	Pollutant	Regional Population	Minimum Number of Air Quality Monitoring Sites
I	Suspended particulates	Less than 100 000	4
	- hi-vol	100 000 to 1 000 000	4 + 0.6 per 100 000 population
		1 000 001 to 5 000 000	7.5 + 0.25 per 100 000 population
		Above 5 000 000	12 + 0.16 per 100 000 population
	- tape sampler		One per 250 000 population up to eight sites
	Sulphur dioxide	Less than 100 000	3
		100 000 to 1 000 000	2.5 + 0.5 per 100 000 population
	- bubbler	1 000 001 to 5 000 000	6 + 0.15 per 100 000 population
		Above 5 000 000	6 + 0.05 per 100 000 population
	- continuous	Less than 100 000	1
		100 000 to 5 000 000	1 + 0.15 per 100 000 population
		Above 5 000 000	6 + 0.05 per 100 000 population
	Carbon monoxide	Less than 100 000	1
		100 000 to 5 000 000	1 + 0.15 per 100 000 population
		Above 5 000 000	6 + 0.05 per 100 000 population
	Photochemical oxidants	Less than 100 000	1
		100 000 to 5 000 000	1 + 0.15 per 100 000 population
		Above 5 000 000	6 + 0.05 per 100 000 population
	Nitrogen dioxide		
	- continuous	Less than 100 000	3
	- bubbler	100 000 to 1 000 000	3
		Above 1 000 000	4 + 0.6 per 100 000 population
			10
II	Suspended particulates		3 hi-vols, 1 tape sampler
	Sulphur dioxide		3 bubbler, 1 continuous
III	Suspended particulates		1 hi-vol
	Sulphur dioxide		1 bubbler
	Nitrogen dioxide		2 bubblers

[a]Source: Environmental Protection Agency 1975.

Table 9. Minimum network for monitoring around designated sources.[a]

Pollutant	Sampling Frequency	Minimum No. of Sites
SO_2	Continuous	3
Total suspended particulates and/or sulphates	Once every 3 days	3

[a]Source: Environmental Protection Agency 1976.

Table 10. Summary of general rules for establishing NAPS network stations.

Type of Station	Pollutants	Regional Population	Minimum No. of Sites	Maximum No. of Sites	Station Site Selection[b] in Order of Priority	Scale of Representativeness
Class I	SO_2, NO_2, CO, O_3, TSP, COH	Above 250 000[a]	1 per 250 000	6	1) in downtown area	Middle
					2) in major residential area with potential for worst air quality	Neighbourhood
					3) in major residential area with potential for poor air quality and in an area of city at least 90 degrees (origin at centre of urban area) from second station	Neighbourhood
					4) in secondary commercial area under influence of heavy traffic	Middle or neighbourhood
					5) in residential area located in a third quadrant different than that for stations 2 and 3	Neighbourhood
					6) in residential area located in the fourth quadrant, or in a third commercial area	Neighbourhood or middle
Class II	Only significant pollutants as required	Above 100 000	1 per 100 000	15, less no. of Class I sites	Identified problem areas based on review of all monitoring data, emissions inventory, meteorological, and geographical data	Mainly neighbourhood
		25 000 to 100 000	1	1		

[a]Population requirements for some urban areas have been waived in order to have adequate national distribution of Class I stations.
[b]For specific probe siting criteria for various pollutants see reference Environmental Protection Service (1977).

4.2.4 Measurement Methods

Table 11 provides a list of standard reference monitoring methods for five pollutants against which other techniques can be compared. However, it is important to note that these reference standards were established in 1970, and significant changes associated with measurement technology have since been achieved. The Environmental Protection Service of Canada has published information concerning the following methods for measuring various pollutants:

1. total oxidants - iodometric titration method (Environmental Protection Service 1972a);
2. sulphur dioxide - West Gaeke method (Environmental Protection Service 1972b)
3. suspended particulates - high volume method (Environmental Protection Service 1973b);
4. carbon monoxide - non-dispersive infrared spectrometry method (Environmental Protection Service 1973a);
5. nitrogen dioxide - chemiluminescence method (Environmental Protection Service 1974); and
6. ozone - chemiluminescence method (Environmental Protection Service 1981a).

Based upon the literature available for this review, it was not possible to determine whether all of these reference standards are still valid. The only reviews of monitoring methods that could be considered to be most current were the reports of EPS (1981b) on sampling and analysis of airborne sulphates and nitrates, the EPA (1982) report that dealt with oxides of nitrogen, and a review of the collection and analysis of organic compounds by Lamb et al. (1980).

The EPS (1981b) report indicated that data on the airborne concentration of sulphate and nitrate particulates from the widely used high volume air sampler glass-fibre filter are subject to substantial errors. The report recommended that the practice of

Table 11. Air quality standards reference methods in use in the U.S.A.[a]

Pollutant	Averaging Time	Reference Method	Principle of Detection
SO_2	1 h, 3 h, 24 h, annual	pararosaniline	colorimetric
Particulate matter	24 h, annual	high-volume sampler	gravimetric
CO	1 h, 8 h	non-dispersive infrared spectrometry	infrared
Photochemical oxidants (ozone)	0.5 h, 1 h	gas phase O_3-ethylene reaction (calibrated against neutral buffered KI)	chemiluminescence
Hydrocarbons (other than methane)	3 h	gas chromatography	flame ionization
NO_2	annual	gas phase	chemiluminescence

[a]After Rossano and Thieike 1976.

determing of airborne sulphates in TSP matter using these filters be discontinued and be replaced with an inert filter medium such as Teflon-coated glass-fibre filters or acid-washed quartz fibre filters.

The EPA (1982) report also refers to the formation of nitrate artifacts on glass-fibre filters. The report concludes that almost the entire urban data base on ambient nitrate concentrations is now considered to be of doubtful validity. On the other hand, new techniques for routine monitoring of nitric acid are available, but have not yet been completely evaluated. The use of long pathlength infrared absorption techniques for nitric acid are considered to be too expensive and not currently adaptable to routine ambient monitoring. The principal findings of the EPA report deal mainly with the measurement methods for NO_2 and NO.

Lamb et al. (1980) summarized the present state of knowledge about the occurrence, sampling, and analytical procedures for the determination of organic compounds in urban atmospheres. The authors concluded that there is no single sampling method that covers the range from gaseous molecules to large particles of organic matter, and a series of stages, involving the progressive removal of first coarse, then fine, and then gaseous material, is required for most complete sampling. The three most useful techniques for monitoring of organic compounds in urban atmospheres were reported as follows:

1. gas chromatography using a flame ionization detector and glass capillary column;
2. high pressure liquid chromatography using a fluorescence detector; and
3. capillary column gas chromatography coupled to a fast-scanning medium resolution mass spectrometer.

Two additional reports on pollutant measurements were also available, but were considered to be of questionable validity since

much of the information in these reviews is approximately 10 years old. Blokker (1978) provides a condensed version of a review by Tanner and Newman (1976) on measurement techniques for atmospheric sulphates. The EPA (1977) conducted a comprehensive review of lead in ambient air that showed that high volume sampling and analysis by atomic absorption spectrometry were the most widely used methods for lead in particulates at that time. However, other methods may now be available, and it is recommended that more recent reviews of sampling and analysis methods be considered in order to determine the current status of measurement techniques.

4.3 URBAN AIR QUALITY MODELLING

In general, air quality assessment and regulatory management rely heavily upon the use of computer models. There appears to be general agreement among investigators that no alternative exists to the use of models, and both government and industry are committed to these models for planning and design.

Early attempts at urban air quality modelling focused on the local scale, and it is only within the last decade that models for the mesoscale (urban scale) have been developed (Olsson 1982). The majority of existing models are merely descriptive in that they provide a quantitative accounting of pollutant dispersion in the atmosphere. Formal management models for decision making by regulatory agencies are relatively few. There is little concern on the part of descriptive modellers about the potential use of models by decision makers, and in the U.S. very few models are considered in air quality implementation plans (Fronza and Melli, eds. 1982).

According to Angle (1981), a clear distinction must be made between research oriented models, which are used to develop an understanding of the physical and chemical processes involved in air pollution, and practical applications-grade models, which are used

in day-to-day decision making for air quality management. Angle quotes the conclusions of the Holcomb Research Institute on the experience in the United States with environmental modelling and decision making:

> "Modelling undertaken in an application-oriented, integrative context (i.e., the synthesis and integration of current knowledge) has a better chance of facilitating decision making than modelling undertaken as basic research. This is not to belittle the role of basic scientific research, but to suggest that modelling applied to environmental management must be undertaken with different and perhaps more pragmatic objectives."

Similarly, Hanna (1982) reviewed atmospheric diffusion models that were applied routinely in various countries around the world, and emphasized the use of practical models as opposed to "research-grade" models for regulatory purposes. According to Hanna, the main criteria for choosing a practical model are that it be simple to apply and understand, inexpensive to run, consistent with similar models, accurate, and well evaluated. For these reasons, nearly all applications make use of either Gaussian plume models or gradient-transport (K) models. Gaussian plume models are most often used in western countries, specifically North America, while K models are used more often in eastern countries, specifically in the U.S.S.R. Although on average the two types of models produce comparable results, Hanna concluded that theoretical differences in the plume-rise formulae of Gaussian models may result in differences in predicted maximum concentrations that are an order of magnitude higher or lower than K model predictions, depending on the specific concentration.

For the most part, dispersion modelling applications these days are primarily concerned with obtaining official sanctions from regulatory agencies for emission levels by industry. Comprehensive regional air quality assessment and planning for both stationary and mobile sources have not been achieved. However, Dennis (1982) has

reported on progress in research at the National Centre for Atmospheric Research and the University of Colorado that will develop a multidisciplinary approach to pollution problems in Denver. In this scheme, dispersion models will form a subset of a causal chain linking activities, emissions, exposure, and effects. An entire set of models is being developed (Table 12) that will be integrated into a scenario model for planning policy options.

However, the technical uncertainties as well as uncertainties in the process of social policy formation are difficult to assess, and the research presented by Dennis cannot be viewed at present as operationally viable.

The following sub-sections will present a general overview of current modelling techniques, as well as an assessment of their limitations and future research requirements as reported by various investigators. No attempt will be made to provide a detailed description of computational formulation since this can be obtained from the references.

4.3.1 Modelling Techniques

In reviewing concepts in air pollution modelling techniques, Benarie (1980) makes the point that the task of attempting to fully review the literature on dispersion modelling is all but hopeless today because "every air pollution control board, every consulting firm and every research unit dealing with air pollution has their own Gaussian dispersion model." In addition, new numerical modelling techniques are also constantly being reported in the literature. The various programmes may differ signficantly in the types of theoretical assumptions employed, in the treatment of the sources (inventory, source height, etc.), in the choice of the dispersion parameters, in the decay constants, in the meteorological input, in the short cuts in the computation, in the display of the results, and the like. To complicate matters, Benarie states that

Table 12. The underlying predictor models for regional air quality policy analysis in Denver, Colorado.[a]

ACTIVITIES MODEL	POLLUTANT CONCENTRATION MODELS
Input-output model of population and economic activity	CO-concentration model
	Haze model
	Oxidant-concentration model
EMISSIONS MODELS	**EFFECTS MODELS**
Stationary-source emissions model	Human-health impact model
Mobile-source emissions model	Standards-violations model
Trip-generation model	Aesthetic-impact model
Vehicle-miles travelled model	Energy-use model
Vehicular emission per mile model	

[a]After Dennis 1982.

most papers or conference reports lack essential information concerning the treatment of computational steps. Frequently, "the scarcity of detail is intentional with the purpose of concealing the difference between mere publicity for the operational application of what is already common knowledge and real progress worth dissemination."

Despite the differences in detailed implementation, the basic concepts have been summarized recently in several review articles by Turner (1979), Hanna (1982) and Eliassen (1982). The following subsections attempt to provide a consistent summary of the different modelling techniques without going into detailed discussion of the formulation. The purpose of the summaries is to provide an overview of the various available techniques as well as some of their strengths and weaknesses for operational application.

4.3.1.1 Gaussian Plume Dispersion Models. The most commonly applied dispersion model on the local scale (i.e., 10 km) for both single and multiple source emissions is the Gaussian plume model (Turner 1979; Hanna 1982; Eliassen 1982). According to Hanna, it forms the backbone of nearly all models in the U.S. EPA system of UNAMAP (Users' Network of Atmospheric Models for Air Pollution) models and in the U.S. Nuclear Regulatory Commission guidelines, and is used by most of the countries participating in the NATO plume-modelling exercise in Frankfurt, Germany. It is so widely used because it is basically easy to apply, is conceptually appealing, and has been evaluated with many data sets.

The theoretical basis of this model is the assumption that the cross-wind distribution of concentration of inert material released from an instantaneous point source is "normal," or Gaussian. Essentially, all Gaussian models are steady-state models in which factors such as wind speed, temperature, emission rates, and mixing height are taken as constants. There is strong

theoretical and empirical evidence to support such assumptions for the case of homogenous turbulence.

The horizontal and vertical dispersion parameters determine how the plume spreads as a function of distance from the source, and are based upon empirically derived values for various classes of atmospheric stability. However, the recommended values of the dispersion parameters may not be valid in situations where wind shear is important, in complex terrain, for light and variable winds, for applications to long-range transport, and for problems in which the plume is still rising due to its buoyancy (Hanna 1982). In urban areas, roughness and stability effects produced by structures create a variable turbulence field for which the basic Gaussian assumptions no longer hold true. Furthermore, while the assumption of a stable gas is quite valid for CO, chemical transformations of some pollutants change the composition of the plume. Consequently, there are many situations in urban air quality analysis in which the use of a Gaussian plume model is invalid. According to Hamburg (1980), Gaussian models fail to give satisfactory predictions for episode modelling, especially during near-zero wind conditions. Benarie (1980) states that the non-Gaussian behaviour of plumes is often ignored by investigators who prefer to deal with a simple, bell-shaped concentration profile.

Basically, Gaussian plume models are designed to describe the short-term statistical diffusion of chemically inert material that is not removed from the atmosphere. By superposition of two or more plumes, Gaussian models can be used to describe the diffusion of emissions from either point, line, or area sources. Although source depletion techniques have been incorporated into Gaussian models in order to account for dry deposition, in reality the use of such techniques introduces significant errors into the computations when the characteristic time for rising through the depth of the plume is less or comparable to the characteristic time for depletion

by deposition (Eliassen 1982). Chemical reactions among pollutants will, in general, destroy the Gaussian distribution of pollutants within the plume; furthermore, it is difficult to incorporate even very simple air chemistry into a Gaussian model (Eliassen 1982). Although Gaussian models have been used in a large number of urban air pollution studies, the effects of variable surface roughness on dispersion parameters is unknown, and there is a lack of relevant empirical data for such situations (Eliassen 1982).

4.3.1.2 Simple Box Models. Since chemical transformations and reactions between pollutants will in general destroy the Gaussian assumption of a plume and will make the superpositioning of many plumes impossible, the modelling of air pollution on an urban scale for area source emissions has often been conducted in the past through the concept of conservation of mass within a fixed "volume element," "parcel," or "box" of air. In its simplest form, the urban airshed is represented by a shallow box with the upper boundary of the box (i.e., the urban boundary layer) being determined by the effective height of turbulent dispersion. Within the box, the urban pollutant source strength is assumed to be uniform and pollutants are well mixed over the height of the box. Using the average wind speed and the average total city-wide pollutant emission rate, a reasonable estimate of long-term average pollutant concentrations can be calculated.

Simple box models emphasize temporal variations and are, therefore, suitable for the study of air pollution climatology and impact assessment. Although spatial resolution is not possible for single box airshed models, some quantitative results of chemical transformations are possible under certain conditions (Venkatram 1978). Unfortunately, the assumptions upon which box models are based are seldom satisfied at any specific receptor site within the box. The most questionable assumptions are those with respect to

the uniformity of pollutant concentrations across the urban area and the flushing rate of the box, which is defined by the mixing height and wind velocity. Venkatram has shown that these assumptions give rise to unrealistically small flushing rates. Rapid temporal changes in either pollutant source strength or wind result in unrealistic predictions of pollutant concentrations. Thus, short-term maximum concentrations cannot be predicted accurately. Furthermore, although chemical reactions can be accommodated within box models, the results of modelling validation are variable. Benarie (1980) reports on the use of a photochemical box model in St. Louis that achieved good agreement between observed and predicted concentrations of non-reactive carbon monoxide, but only fair agreement in the temporal variation of reactive species (i.e., NO_x, NO_2, and O_3). Maximum calculated and observed hour-averaged ozone concentrations showed poor correlation between predicted and observed levels.

In order to improve on the spatial resolution of single box models, the urban area can be divided into a grid of multiple neighbouring boxes in both the vertical and horizontal directions. Benarie reports on a number of studies using multi-box models that included adjustments for variable height of the inversion layer, terrain elevation, and variable wind flow in each box. Transport from box to box through complex terrain is handled by a climatological streamline pattern influenced by prominent terrain features, whereas the vertical extent of the box layer is determined by climatological averages of inversion base heights.

A variation of the single box model, called a slug model, was reported by Venkatram (1978). The slug model uses an exact mass conservation equation and is capable of simulating the dynamics of air pollution more realistically than the oversimplified box model. Venkatram suggests that the slug model can be used as an alternative to the simple box model for qualitative and limited quantitative analysis of pollutant concentrations during stagnation episodes.

4.3.1.3 Numerical Models. Given the limitations associated with the application of Gaussian plume models and box models for short-term urban air quality assessment, a number of alternative methods have been developed that employ a three-dimensional numerical solution of the diffusion equation to estimate the mean pollutant concentration. Whereas a Gaussian model makes certain assumptions that lead to an exact, analytical solution of an inexact diffusion equation, numerical modelling techniques provide an inexact solution to a more precise diffusion equation, integrating the equation step by step over time. The Gaussian approach is statistical, using the overall description of wind and stability to estimate the statistical, steady-state behaviour of a plume over distance from a source. It does not trace the movement of the plume through time and space. Numerical models, on the other hand, apply the diffusion equation at each point in space over a series of time intervals.

According to Budiansky (1980), there are three general approaches to numerical modelling, all of which rely upon a solution of the gradient-transport (K) equation.

> In the Eulerian formulation, a fixed coordinate system, or grid, is laid out over the entire region of interest. The concentration of a pollutant in each square of the grid is then calculated by explicitly solving the equation, using numerical methods and the help of a computer, over a series of small time intervals. In squares which contain sources, a source term is added to the right side of the K-theory equation.
>
> This approach is most useful for situations in which there are multiple sources or for which predicted concentrations are needed for the entire region.
>
> The Lagrangian formulation, on the other hand, considers a coordinate system moving with the local mean winds. This approach is particularly useful for modelling transport over a long distance or when the effect on only a particular receptor site is of concern - in other words, when there is no need to calculate concentrations over an extensive array of

fixed locations. While this saves on computer space and time, it leads to results which can be difficult to interpret, since the coordinate grid is distorted as it twists and turns with the local winds. A subset of Lagrangian models, trajectory models apply the Lagrangian formulation to a single moving cell, thus avoiding the grid distortion. In this case, however, turbulent diffusion must be calculated from external data, and is in practice usually neglected altogether.

The particle-in-cell method is a hybrid approach. Here, the source emissions are divided into individual Lagrangian cells, each of which is tracked over a fixed coordinate system. The concentration in each fixed grid square is then calculated simply by counting up the number of these cells present in each square.

The major drawbacks to the use of numerical models are the need for more detailed information on meteorological parameters (particularly the wind field over the entire region), emission sources and rates, and observed pollutant concentrations for comparison with predicted levels. Since numerical modelling involves the integration of the equations at each step in time, truncation errors can accumulate through successive integration steps. The truncation errors can be reduced by either shortening the time steps or increasing the grid density, but either way requires large increases in computer capacity and run time. According to Turner (1979), the additional efforts in data requirements and computer time do not justify the use of numerical models because, in Turner's opinion, Gaussian models can still be improved to produce comparable results despite their built-in limitations. Sklarew (1980), however, strongly disagrees by pointing out that while the numerical models can make use of better data inputs when these are available, such models do not necessarily require this information, and indeed can be used with the input that is required by Gaussian models.

Deardorff (1978) evaluated different modelling approaches and concluded that whereas Gaussian modelling was more suitable for solving problems of vertical diffusion from the surface and for

short-range diffusion from low-level sources, the numerical approach was better suited to intermediate (mesoscale) range diffusion from elevated sources (single and multiple), and for fumigation situations. In addition, numerical techniques have shown greater success in modelling real-time episodes, and are particularly useful for photochemical modelling.

Unlike the Gaussian modelling techniques, comparisons between various numerical models have not been made to any great extent. This is due in part to the fact that many of these models are relatively new and have not been thoroughly validated. As mentioned previously, lack of complete documentation also hampers such comparisons.[1] Demerjian (1976) provides a review of mathematical modelling approaches from the early 1970s.

According to Hanna (1982), most numerical modelling formulations using the gradient-transport (K) model in the U.S. have involved simulations of the formation of photochemical smog in urban areas. For these situations, emission sources were widespread, and horizontal diffusion was not as important; most other photochemical models treat horizontal diffusivity very crudely. Therefore, on the basis of literature available for this review and scope of this study, no conclusions can be drawn about the strengths and weaknesses of available numerical models.

4.3.1.4 Receptor-Oriented Models. The classical dispersion modelling techniques discussed in the preceding sub-section utilize input from emissions inventories and meteorological data to predict ambient concentrations of air pollutants. According to Turner (1979), the accuracy of a given model for a particular application

---

[1] A rare example of a fully documented model reported by McRae, Goodin, and Seinfeld (1982) has been evaluated in Los Angeles, and is discussed in Section 4.3.2.

is more dependent upon the quality of the emission and meteorological data used for input than upon the theoretical assumptions employed in the models. Furthermore, these source-oriented models usually do not include contributions from fugitive process emissions and dust, and are incapable of providing information on sources of particles in certain size ranges, particles bearing certain toxic substances (e.g., lead), or particles that have a role in special problems such as visibility degradation.

Consequently, a different set of receptor-oriented models for particulates is being developed that attempts to assess the contributions from various sources based on the composition of samples at monitoring (receptor) sites. Using statistical analysis of the chemical composition of many samples, the concentration patterns of total suspended particulates (TSP) within the urban area are correlated with the composition of particles released from all important types of sources in the urban area (Gordon 1980). Theoretically, the observed concentration pattern is a linear combination of the patterns of TSP emitted from all sources, each weighted by a source-strength term.

Such an assumption is an obvious oversimplification, for it ignores the fact that there are often large variations in TSP emissions within a given source class, and assumes that all particles remain unaltered between the source and the receptor. In fact, a substantial fraction of fine particulates is formed from gases such as SO_2 and hydrocarbons after emission, and very large particulates may be removed by preferential fallout between the source and receptor.

Nevertheless, receptor models of ambient TSP can provide a useful complement to more classical dispersion modelling techniques, particularly for local decision-making applications aimed at achieving compliance with TSP air quality standards, and for industrial development impact assessment. According to Gordon, receptor-model results are already more accurate than predictions by

source-oriented techniques in most cases. A major drawback to their use, however, is that current methods of conducting stack-emissions testing provide data that are unsuitable for receptor-model correlation, and a new design for source measurements is required.

4.3.2 Limits of Model Accuracies

As identified by Wilson and Peters (1979), the four major input components and assumptions required by most modern models are as follows:

1. emissions inventory;
2. meteorological data;
3. meteorological dispersion and/or chemical transformation algorithms; and
4. ambient air quality data.

The accuracy of predicted pollutant concentrations for any model is dependent as much upon the accuracy and completeness (both spatial and temporal) of the input data as upon the precision of the dispersion and chemical transformation algorithms. Furthermore, the evaluation of the predictions is also dependent upon the representativeness of the recorded air quality data.

Budiansky (1980) estimated that the accuracy of currently available dispersion models may range from 30 percent to a factor of 2, or even 10, depending upon the pollutant, the averaging time, the spatial scale, and the terrain, as well as the basic model formulation. Model input requirements for single or multiple source Gaussian models are relatively small:

1. emission source strength;
2. effective height of emissions;
3. wind speed and direction at effective height of emissions;
4. stability of the atmosphere and mixing height; and
5. sampling time and location of receptors.

The simplicity of the Gaussian data inputs results in relatively accurate predictions for the limited conditions for which the Gaussian models are applicable. Errors in such cases are equivalent to errors in emission inventories.

By comparison, the input requirements for numerical models for photochemical transformation studies can be enormous. For example, the EPA (Wada et al. 1979) in the U.S. prepared an estimate of the level of effort required for the application of photochemical models (Eulerian grid and Lagrangian trajectory) in urban ozone studies. By specifying in detail the types of data required, Wada et al. estimated that the time required to conduct a full photochemical modelling program could range from 64 to 625 weeks. The lower figure is applicable to areas with extensive existing data that are easily converted to appropriate model inputs. The higher figure represents the estimate of time required to acquire extensive additional data for model application. The costs associated with a full modelling program will be determined by the adequacy of the existing data base. When adequate data are available, Wada et al. estimate that model preparation and performance evaluation can normally be carried out for about $75 000 to $150 000. "However, if an emissions inventory must be compiled and if a short-term intensive field program is mounted to collect additional air quality and meteorological data, then the overall costs may run as high as $500 000 to $750 000." The cost of supplemental emissions and aerometric monitoring programs such as the EPA's Regional Air Pollution Study in St. Louis, a city that has been extensively studied in the past, may exceed several million dollars. Without the input data, however, the accuracy of the photochemical models will be decreased substantially, while the absence of adequate air quality data will prevent a full evaluation of the accuracy of the model's predictions.

An example of the level of effort required to evaluate the performance of a photochemical model for a single 48-hour period in the South Coast Air Basin around Los Angeles was reported by McRae, Goodin, and Seinfeld (1982). Table 13 summarizes the aerometric and emissions data used in the evaluation. Data were obtained from a total of 10 organizations. Despite the extensive data inventory, the authors reported that further model development was hampered in many areas more by the paucity of measurements than by the understanding of the basic physics and chemistry. Data requirements, over and above those listed in Table 13, considered necessary for further research are listed in Tables 14 and 15.

Given the difficulty of evaluating alternative modelling techniques, the reluctance on the part of regulatory agencies in the U.S. to use models other than the approved "off-the-shelf" Gaussian models is not surprising. Lacking sufficient data, the performance and accuracy of alternative models is often judged with respect to the performance of Gaussian models, which are themselves of uncertain validity and accuracy. However, in Mirabella's (1980) opinion, it is doubtful whether currently approved "off-the-shelf" Gaussian models would meet the performance and accuracy criteria that are likely to be imposed on any alternative model.

Mirabella's opinion was supported by Hamburg (1980) who stated that in official circles all other modelling approaches are considered suspect, and can achieve respectability only through monumental validation efforts. In Turner's opinion, non-Gaussian approaches are necessary for modelling chemical transformations, pollution build-up over time, and for complex variations of wind field over the modelled area. However, for simplified situations, Gaussian models will continue to be applied and improved.

Therefore, it may be concluded that, at present, there is no simple solution to the problem of choosing models for air quality management. There is a need to set definitive and quantitative meteorological, topographical, source type criteria for the

Table 13. Summary of aerometric and emissions information available for 1974 June 26-28 for the south coast air basin.[a]

TYPE OF DATA	NATURE OF DATA COLLECTED	REMARKS
Air Quality Data		
Surface pollution concentration	55 air quality monitoring stations	Data are hourly averaged and include measurements of CO, NO, NO_2, O_3, THC, RHC, and SO_2.
Pollution concentrations aloft	None	Estimates of vertical concentration profiles were derived from detailed field measurements collected from different periods.
Meteorological Data		
Surface winds	63 surface wind monitoring stations	Data include hourly averaged and instantaneous values.
Upper level winds	Radiosondes at Edwards AFB (0400 PST), Pt. Mugu (0400, 1000, and 1500 PST), and San Nicholas Island (0930 and 1500 PST). Pibals at LAX (0530 and 1130 PST) and El Monte (0600 and 1230 PST). Aircraft spiral at Riverside (0600 PST)	
Mixing depths	Aircraft spiral at Riverside (0600 PST). Radiosondes at LAX (0530, 1030 PST), El Monte (0600, 1230 PST), Pt. Mugu (0400, 1000, 1500 PST), and San Nicholas Island (0930, 1500 PST), and Edwards AFB (0400 PST). Continuous acoustic sounder at El Monte	Data are instantaneous except for continuous acoustic sounder at El Monte.
Surface temperatures	Temperatures at 14 stations	Data are hourly averaged values.

Continued . . .

Table 13. Concluded.

TYPE OF DATA	NATURE OF DATA COLLECTED	REMARKS
Meteorological Data (cont'd)		
Solar radiation	Radiation measurements at UCLA and LAX	Data are hourly averaged and daily averaged values.
Humidity	Humidity at 14 stations	Data are hourly averaged values.
Cloud cover	Cloud cover at 7 airports and 2 other locations	Data are instantaneous values recorded every hour.
Emissions Data		
Traffic	Emissions estimates derived from the LARTS transportation model and the ARB FWY011 emissions model	Peak, off-peak, and total emissions rates for THC, SO_2, NO_x, and CO are available. Percentage of hot and cold starts are included in the inventory, but they are not spatially or temporally distributed; vehicle speed distributions and types (four classes) are included.
Refinery	Emissions for organic gases, NO_x, CO, and particulates estimated for 28 facilities	
Aircraft	Gridded emissions estimates for all major airports in inventory region	
Power plants	Emissions estimates of NO, NO_2, and CO for each plant in inventory region	Diurnal distribution of emissions based on inspection of daily operating logs.
Distributed area sources	Emissions estimates for organic gases, NO_x, and CO	
Other stationary sources	Emissions estimates for organic gases, NO_x, and CO	

aAfter McRae, Goodin, and Seinfeld 1982.

Table 14. Summary of additional meteorological measurements needed for model evaluation.[a]

Wind Measurements
Vertical shear distributions
Flow patterns close to mountains (upslope flows)
Magnitudes of nocturnal drainage flows
Quantitative evaluation of monitoring site exposure
Characterization of the effects of surface roughness
Mixing Height Distribution
Increased spatial and temporal resolution of mixing height
Effective mixing height distributions close to mountains
Solar Radiation
Detailed spatial and temporal measurements of UV flux

[a]After McRae, Goodin, and Seinfeld 1982.

Table 15. Summary of additional chemical measurements needed for model evaluation.[a]

Concentration Measurements - General Aspects
Quantitative evaluation of interference effects
Detailed characterization of monitoring site exposure
Establishment of bounds on measurements due to errors and averaging
Improved resolution of vertical concentration distributions
Routine measurements of certain non-criteria pollutants
Hydrocarbon Measurements
Spatial and temporal variations of hydrocarbon reactivities
Characterization of aldehydes and natural hydrocarbons
Need for increased species resolution beyond THC-RHC-CH_4
Background Air Quality
Values away from urban region
Vertical profiles of ozone
Hydrocarbon concentration and composition
Concentration of NO, NO_2, and O_3
Source Profiles and Emission Factors
Detailed emissions distributions from mobile sources
Chemical composition and solvent utilization by industries
Extent and magnitude of emissions from gasoline evaporation
Industrial fuel usage patterns
Improved characterization of emissions from area sources

[a]After McRae, Goodin, and Seinfeld 1982.

application of various types of models (Thurston 1980). Since any model will have computational assumptions that are valid in some situations but not in others, air quality management programs must expect to have available several different types of models in order to be able to simulate various situations.

4.3.3 Future Modelling Requirements

Turner (1979) provided a summary of the eleven EPA-approved "off-the-shelf" models (UNAMAP). All are based on the Gaussian modelling approach and are, therefore, limited in their applicability. Further information about the models is also available in the references cited by Turner, as well as from Benarie (1980).

According to Turner, the following simulation requirements are not available from any of the approved UNAMAP models:

1. atmospheric reactions and transformations;
2. removal of particulate matter by settling and deposition;
3. dispersion of pollutants in complex terrain for 3-h and 24-h periods;
4. changes in roughness and vertical thermal structure at land-water interfaces;
5. maximum 24-h concentration episodes in urban areas during periods of light and variable winds; and
6. modelling aerodynamic downwash.

Some of these requirements can be met with numerical modelling techniques, particularly for photochemical transformations. However, no comprehensive summary of capabilities of existing alternative models is currently available for reference. Demerjian (1976) reviewed the status and shortcomings of mathematical models for chemical and physical processes that were considered to be state of the art at that time. A more recent summary would be required prior to selection of a model for air quality management.

4.4 EFFECTS/CONSEQUENCES OF AIR POLLUTION

The one unequivocal conclusion that may be drawn from the literature on the effects of urban air pollutants is that there is sufficient qualitative evidence to justify concern and action on the part of regulatory agencies about the ambient concentrations of pollutants. However, in most cases, it is very difficult to establish the degree of seriousness of the various effects of any single pollutant.

With respect to health effects, for example, air pollution has been associated with pulmonary dysfunction. Difficulties persist, however, in the interpretion of health effects from exposure to ambient air pollution, partly due to the difficulties involved in estimating exposure levels (Silverman et al. 1982). Extreme examples of air pollution episodes are acknowledged to be directly related to acute health effects such as the case of the London smog in 1952, which was held to be responsible for the deaths of approximately 4000 people (Oke 1981). Similarly, laboratory exposures of human subjects to various levels of individual pollutants (e.g., NO_2) have identified hazardous levels for these species. However, it is recognized that ambient air is composed of complex mixtures of pollutant species, and laboratory studies of exposure to specific single pollutants may under- or over-estimate effects. Studies of short-term exposure in laboratory chambers to mixtures of species have been conducted, but the results of such studies are difficult to relate to effects of chronic, long-term exposure to ambient levels of air pollutants (Environmental Health Directorate 1982).

In the past, a major source of difficulty in analysing chronic health effects of long-term exposure has been the doubtful representativeness of ambient air quality data. Silverman et al. (1982) state that, until recently, studies of health effects of air pollution have had to rely on measurements of pollutant concentrations at fixed monitoring locations. Since these stations were

established to evaluate compliance with air quality standards, their location was meant to be representative of ambient air quality at the neighbourhood scale, rather than a measure of population exposure at specific sites of human activities. Many studies have shown that there are substantial differences between air pollution levels measured at fixed location monitoring stations and the levels to which people are actually exposed in the course of daily activities. Silverman et al. suggest that a more realistic approach to the study of health effects of air pollutants would make use of "personal exposure" samplers in an extensive monitoring network based upon activity profiles of the population.

Table 16 lists the acknowledged (both quantitative and qualitative) effects of some anthropogenic air pollutants as summarized by Rodhe (1982) from published WHO and WMO sources. Rodhe makes a distinction between the direct effects of a compound itself and the indirect effects of secondary reaction products. Therefore, a compound may have an effect on the local climate, which may in turn affect concentrations of other compounds and lead to effects on ecosystems. Rodhe makes no attempt to qualify the seriousness of the various effects. It is important to note that Table 16 is not the only, or the best, arrangement of compounds versus effects. Other investigators may differ in their conclusions about direct and indirect effects of some pollutants.

4.4.1 Health Effects

Air pollution affects virtually the entire urban population to some degree (Winthrop 1973). Historically, adverse health effects of urban air pollutants have been associated mainly with SO_2 and aerosols.

Chipman (1977) states that there is little doubt that sulphur compounds affect health, but that there are uncertainties about the doses that are likely to affect the health of an appreciable number of people. Oxford (1983) has summarized some of

Table 16. Types of effects* of some important air pollutants.[a]

	Health Effects	Damage to Materials	Damage to Ecosystems	Acidification of Precipitation	Effects on Stratospheric Ozone Layer	Effects on Climate
Gaseous compounds						
SO_2	D,I	D,I	D	D,I		
NO_x(NO,NO_2)	D,I	D,I	D,I	D,I	D	I
N_2O					I	D
CO	D					I
CO_2					I	D
Chlorofluoro-carbons (CFC's)					I	D
O_3	D	D	D			D
Hydrocarbons	D	I	I	I		I
Krypton-85						I
Particulate matter						
Aerosol particles in general	D					D
Sulphate- and nitrate-containing particles	D	D		D		D
Soot						D
Heavy metals	D		I			
Radionuclides	D		I			

*D indicates direct effects and I indirect effects.

[a]After Rodhe 1982.

the reported effects attributed to the inhalation of SO_2 and H_2S, although a generally accepted quantitative assessment of these effects is still not available. These effects are presented in tables 17 and 18; Table 19 lists Alberta air quality standards for these compounds.

Ozone is of particular concern because some adverse effects, such as eye irritations, may show up at concentrations that are only slightly higher than those occurring in unpolluted air (Rodhe 1982, Legge et al. 1980). In the past, ozone has been associated with increased susceptibility to pulmonary infection, pulmonary edema, and changes in the surface tension, elasticity, and aging of tissue (Legge et al. 1980). More recently, however, NO_2 has been identified as the oxidant responsible for effects on health (Environmental Health Directorate 1982). Specifically, "reduced resistance to respiratory infection appears to be the most sensitive indicator of damage produced by long-term exposure to nitrogen dioxide in the general population." (p. vi)

Basuk and Nichols (1978) reviewed the NO_x hazards to human health in Canada, and reported that there were adequate data to allow estimates of symptoms and measurable changes in pulmonary function in the normal population caused by oxides of nitrogen. Within the present state of knowledge, the authors concluded that the concentrations of NO_x measured in Canadian urban areas did not pose a general health hazard to the population. However, some localities, notably Vancouver, Edmonton, Sarnia, Toronto, Montreal, and the Maritimes, consistently exhibited high concentrations that warranted concern and possibly regulatory control of emissions.

Based upon chamber and epidemiological evidence of effects from exposure to NO_2, the Environmental Health Directorate (EHD), Health and Welfare Canada, has recommended revised ambient levels for air quality objectives. These objectives are compared with current maximum acceptable limits of the National Air Quality Objectives (1976) for Canada and the Alberta Air Quality Standards

Table 17. Summary of reported effects of inhalation of sulphur dioxide.[a]

Concentration (ppm)	Effect or Comments
0.035	WHO-estimated threshold for respiratory effects from long-term exposure (increased respiratory symptoms in adults and children above this level)
0.08	WHO-estimated threshold for worsening the condition of patients with existing respiratory disease from short-term exposure (e.g., increased asthma attack rate, increased illness score among bronchitics)
0.18	WHO-estimated threshold for excess mortality among the elderly or chronically sick from short term exposure
0.35	Mortality rate three times normal in epidemiological study, London, England
0.3 to 1.00	Detectable by taste
0.75 to 1.00	Lowest level causing detectable decrease in FEV, FVC, and MMFR in human lab studies (2-h exposure)
8 to 12	Immediate irritation to throat
20 to 50	Immediate irritation to eyes, nose, and throat, inducing sneezing, rhinorrhea, and cough

[a]After Orford 1983.

Table 18. Concentrations of H_2S and human health effects.[a]

Concentration (ppm)	Classification	Effects
0.3	Odour threshold	Odour apparent
10	Threshold limit value	None
20 to 50	Irritation - minimal	Minimal eye and lung irritation May have digestive upsets
50 to 150	Irritation	Olfactory nerve paralysis can occur at 150 ppm
150 to 300	Irritation - severe	Loss of smell in ± 30 min Severe eye irritation Severe lung irritation
300 to 500	Dangerous	Loss of smell in ± 30 min Severe eye irritation Severe lung irritation with pulmonary edema after 30-min exposure
500 to 700	Life-threatening	Systemic symptoms within one hour. Headache, dizziness; unconsciousness and death within 4 to 8 h Serious irritation to respiratory tract and eyes (conjunctiva and epithelium) within 30 min Coughing, bronchitis, pharyngitis, dyspnea, possible pulmorary edema, photophobia, conjunctivity, and keratitis

[a]After Greenhill 1978, cited by Orford 1983.

Table 18. Concluded.

Concentration	Classification	Effects
700 to 1000	Life-threatening	Systemic effects predominate over local irritant effects. Systemic symptoms within 30 min. Collapse, asphyxia, and death within one hour
100 to 2000	Life-threatening	Systemic effects predominate over local irritant effects. Immediate systemic symptoms. Stimulation of respiration (hyperpnea), followed by respiratory inactivity (apnea), collapse, asphyxia, and death within 30 min
+2000	Lethal	Systemic effects predominate over local irritant effects. Paralysis of respiratory centre, immediate death

Table 19. Alberta air quality standards.[a]

Contaminant	Alberta Standards ppm ($\mu g/m^3$)	
Sulphur Dioxide		
Annual arithmetic mean	0.01	(30)
24-h average	0.06	(150)
1-h average	0.17	(450)
0.5-h average	0.20	(570)
Occupational exposure limit (8 h)	2.00	(5 700)
Short-term occupational exposure limit (15 min)	5.00	(14 300)
Hydrogen Sulphide		
24-h average	0.003	(4)
1-h average	0.010	(14)
0.5-h average	0.012	(17)
Occupational exposure limit (8 h)	10.000	(14 000)
Short-term occupational exposure limit (15 min)	15.000	(21 000)

[a]After Orford 1983.

in Table 20. Reported effects on human health caused by inhalation of NO_2 are summarized in Table 21.

The EHD conclusions about health effects are supported by the Environmental Protection Agency of the U.S. based upon studies on animal susceptibility to respiratory infections (Environmental Protection Agency 1982). Many other effects have also been noted in animals exposed to NO_2 concentrations similar to those causing increasing susceptibility to respiratory infections. However, the Environmental Protection Agency notes that these have not usually been demonstrated in humans, although the potential for their occurrence should not be ignored. Placing their conclusions into perspective, the EPA notes that:

> ambient air NO_2 monitoring results in the United States indicate that peak 1-h NO_2 concentrations rarely exceed 0.4 to 0.5 ppm. Such peaks occurred during 1975 to 1980 in only a few scattered locations in the United States, e.g., Los Angeles and several other California sites. Also, during that period, annual average NO_2 concentrations exceeding 0.05 ppm[1] were only found in a relatively few scattered locations, including population centers such as Chicago and Southern California.

Carbon monoxide has also been recognized as a health hazard because of its known biological effect on the reduction of oxygen in the bloodstream (Winthrop 1973). Concern has been expressed in studies that have drawn attention to the existence of substantial discrepancies between CO levels detected at government monitoring stations and the much higher concentrations encountered by pedestrians in large metropolitan areas (Wright et al. 1975; Smith et al. 1974). Laboratory experiments of exposures to CO concentrations of 15 ppm for eight hours or more have produced impairment in time interval discriminations, while levels of 30 ppm

---

1 Note that for 1979, the last year of published Air Monitoring Reports in Alberta, the annual average NO_2 concentration at the downtown (CDMU) station in Calgary was 0.05 ppm.

Table 20. Comparison of federal, provincial, and recently proposed standards for ambient NO_2 concentrations.[a]

	Government of Canada			Alberta Levels	EHD (1982) Proposed Levels
	Maximum Desirable	Maximum Acceptable	Maximum Tolerable		
1-h	-	400	1000	400	750
24-h	-	200	300	200	470
annual	60	100	-	60	100

[a]All units in $\mu g/m^3$. For comparable units in ppm, see tables 1 and 2 of Section 2.

Table 21. Summary of reported effects of inhalation of nitrogen dioxide.[a]

Concentration (ppm)	Effects or Comments
0.05 to 0.075	No effect on prevalence of chronic respiratory symptoms.
0.08 to 0.15	Increased respiratory disease in children.
0.11 to 0.42	Odour threshold.
0.50	WHO-estimated threshold for respiratory effects of short-term exposure.
0.7 to 5[b]	Increased airways resistance in laboratory studies after 10-min to 2-h exposure.
10 to 20	No discomfort.
100 to 150	Delayed pulmonary edema after 30- to 60-min exposure.
200 to 700	Fatal pulmonary edema after less that one-minute exposure.
More than 1700	Lethal in minutes.

[a]Source: Orford 1983.

[b]The Alberta air quality standard for an 8-h occupational exposure limit is currently 5 ppm (9000 $\mu g/m^3$).

have elicited impaired psychometer performance (Winthrop 1973). In downtown Toronto, street-level CO concentrations have been shown to vary from 10 to 50 ppm, depending on wind speed and direction, atmospheric stability, traffic density, and the height of nearby buildings. Santini (1976) states that highest CO concentrations (and associated violations of CO standards) are most often caused by queuing of vehicles at intersections or by other impediments to traffic flow. Wright et al. (1975) have recommended that appropriate solutions to reducing high levels of CO would be as follows:

1. limit vehicular access to narrow, crowded streets;
2. improve planning and engineering in highway design and traffic flow;
3. control vehicular emissions; and
4. upgrade mass transit facilities.

Hileman (1981) states that recent health studies have shown that inhalable particulates also have adverse effects on human health.

> Generally speaking, fine and coarse particles up to 10 microns can be absorbed by the alveolas region of the lung. Deposition in this region is of special concern because the body may take weeks to years to remove these particles. They can affect the lungs in several ways: They may aggravate chronic lung disease by disturbing normal ventilation and causing a reflex constriction of blood vessels that supply part of the lungs; they may also cause inflammation, fibrosis, and other conditions of the lung. (p. 985)

> Winthrop (1973) states that:
> The ability of particles to accentuate the adverse physiological effects of simultaneously inhaled gases is one of their most important aspects. Particles, however, may be quite complex in their chemical composition. Materials found in airborne particles include aliphatic and aromatic hydrocarbons, acids, bases, phenols, and a wide range of metallic elements. Any one of these substances, when present in airborne particulate matter, may independently exert its own pathological or other physiological effect when inhaled.

According to Natusch and Wallace (1974), many studies have shown that a number of potentially toxic trace species, including lead, cadmium, antimony, selenium, nickel, vanadium, zinc, cobalt, bromine, manganese, sulphate, and benzo(a)pyrene, are present in fine particles in most urban aerosols. Many of these, when deposited in the lungs, are known or potential carcinogens. Of special significance is the exposure of urban populations to toxic heavy metals in aerosols, particularly airborne lead from vehicular emissions. The EPA (1977) in the U.S. states that:

> During periods of maximum traffic density on freeways, airborne concentrations of lead immediately adjacent to the freeways may reach 20 $\mu g/m^3$ for a few hours. In the immediate vicinity of large stationary sources having no air pollution controls, concentrations of airborne lead may reach 300 $\mu g/m^3$ under unfavorable meteorological conditions. Consequently, exposure via inhalation of airborne inorganic lead particles may vary by a factor of at least 100, depending on location and activity patterns. (Environmental Protection Agency 1977).

And:

> With the exception of those living in areas with primary lead smelters, most populations exposed to lead live in urban areas. Residents of the central city are at the highest risk in these urban areas. Therefore, for other than point stationary sources of lead, it is the urban population that is at risk, and in particular, central city residents. (Environmental Protection Agency 1977).

Both clinical and epidemiological data uniformly demonstrate the relationship between the actual uptake of airborne lead and adverse health effects. Studies measuring the quantity of lead in urban areas have consistently demonstrated an additive relationship between blood lead levels and exposure to multiple sources. The cumulative effects include anemia in both children and adults, neurological damage, and renal effects related to prolonged exposure to lead.

4.4.2 Nuisance Effects

Nuisance effects in urban areas can include the following:

1. soiling of paint, windows, and laundry;
2. interference with growth of vegetation;
3. unpleasant odours;
4. aesthetic visibility impairment (i.e., brown smog, haze); and
5. corrosion of materials.

Public complaints to government agencies about odours and particulate matter (dust) are the two most highly ranked sources of public dissatisfaction with ambient air quality (Dworkin and Pijawka 1981). Schroeder (1975) has stated that offensive odours are capable of producing nausea, vomiting, and headaches, while in some individuals they can result in appetite loss, impaired nutrition, curtailed water intake, disturbed sleep, upset stomach, and hampered breathing. At elevated concentrations, some (but not all) annoying odours may also cause nasal irritation. Van Gemert and Nettenbreijer (1977) have compiled a comprehensive list of odour threshold values in air for various compounds. They note that the sensitivity of individuals to substances may vary by a factor of 100 to 1000.

Damage to vegetation as a result of direct contact with leaves and needles has been documented for SO_2, NO_x, and O_3, while indirect effects of toxic substances, such as heavy metals, on soils and waters have been researched extensively. Effects on ecosystems caused by the deposition of acid substances has been an ongoing subject of research in Europe and North America for decades, and is well substantiated. Rodhe (1982) states that the most important sources of acidity in precipitation in industrial countries are SO_2 and NO_x. Some of the SO_2 is oxidized to sulphuric acid in liquid phase reactions, while a significant part of the acid is also formed by gas phase photochemical processes and later incorporated into cloud and raindrops. It is estimated that

in northern Europe, sulphuric acid accounts for two-thirds and nitric acid for about one-third of the acidity of precipitation.

SO_2, NO_x, and acid aerosols at high concentrations are responsible for significant damage to materials through corrosion in urban areas. Ozone and other oxidants in photochemical smog can damage rubber and various synthetic materials, while hydrocarbons and NO_x can cause indirect damage to materials because of their importance to the formation of ozone (Rodhe 1982). All of the compounds involved in photochemical transformations contribute in some degree to the formation of brown smog -- also a significant source of public annoyance.

4.4.3 Effects on Climate

Rodhe (1982) lists the following as being possible effects of air pollutants on climate:

1. interacting with solar radiation (mainly by aerosol particles containing soot);
2. trapping outgoing long wave radiation (mainly by CO_2, but also O_3, N_2O, CFCs, and some minor gases);
3. affecting the size distribution of cloud droplets and thereby affecting their optical properties (aerosol particles); and
4. changing the electrical properties of the air and thereby possibly affecting the dynamics of thunderstorms.

The effects of pollutants on incoming and outgoing radiation are particularly significant to the formation of the urban heat island and also affect the chemical reactions of various pollutants within the urban atmosphere. These aspects of the urban boundary layer have been reviewed extensively by Oke (1981).

The effects of aerosols on the optical properties of the atmosphere have also received much attention in scientific literature. "Atmospheric visibility is a function of the transmission of light through the air and the ability of the eye to identify an object by its contrast with the background" (National Research Council Canada 1982). The principal optical effect of atmospheric aerosols is the reduction of visibility with increasing aerosol loading due to the reduction of radiative energy. The scattering and absorption of light by aerosols is dependant upon the following factors:

1. particle size distribution;
2. refractive index;
3. shape of particles;
4. relative humidity; and
5. wavelength of incident light.

Despite the large amount of research which has already been devoted to the study of aerosol effects on visibility, the NRCC has concluded that there is a need for further studies to determine the relationship between visibility and particle mass loading and to assess the effects of aerosols on the radiation and energy budgets of urban areas. The NRCC (1982) states:

> Although it has been generally accepted that airborne fine particles are responsible for much of the reduction in visibility, especially in areas of relatively low particle mass loadings, the concentration and chemical composition of such particles can vary significantly on both a spatial and temporal basis. Numerous attempts have been made to correlate particle chemical composition with visibility reduction; however, such a correlation must be considered tenuous since a chemical constituent's contribution to aerosol mass loading may not equal its contribution to visibility degradation. Some field studies have demonstrated that there are significant positive correlations between sulfate concentrations and visibility, especially in nonurban areas.

The NRCC (1982) study also concluded that, aside from visibility reduction, all other supposed effects of aerosols on climate must be considered only qualitative in nature, and further studies are necessary to establish quantitative relationships between cause and effect.

> Although numerous studies have attempted to define cause and effect relationships between atmospheric particle loading and planned or inadvertent weather modification, very few have demonstrated statistically significant results. There is a general consensus that urban areas enhance rainfall in downwind areas; however, the significance of modifying factors such as particle generation, urban heat island and urban topography have not yet been quantified. Atmospheric electrical properties may be altered by the introduction of airborne particles, although the consequences of either short- or long-term alterations are not known.

Consequently, the NRCC has recommended that further studies on the role of atmospheric fine particles in such processes as rain and snow alteration, fog dissipation, hail suppression, and the alteration of atmospheric conductivity be further examined under Canadian climatic conditions.

4.4.4 Actual versus Perceived Effects

In reviewing the relationship between actual ambient levels of air pollution and public perception of air quality in Toronto, Dworkin and Pijawka (1981) concluded that community awareness, concern, and attitude toward environmental quality are closely related to media coverage and direct individual experience with tangible effects of the less hazardous pollutants that produce odour, dust, eye, and respiratory irritation, and poor visibility or haze. On the other hand, awareness and concern for the presence of more toxic substances are more closely related to media coverage alone. For example, Dworkin and Pijawka (1981) state the following:

> Decline in concern over pollution levels is reflected by the corresponding decrease in media recognition of the pollution problem in contrast to increasing concern with inflation and unemployment. Although concentrations of most pollutants in Toronto have declined in the past few years which include gases and

> particles so small as to be imperceptible, concentrations of oxidants continue to produce visibility problems. Yet despite these air quality data, the response of the sample population suggests alternatively that visibility has improved, air quality in general has deteriorated and concern with air pollution on the whole decreased. (p. 16)

Dworkin and Pijawka (1981) suggest that the lack of a positive relationship between improvements in air quality and an individual's perception that air quality has improved may be explained by a decline in media attention to air pollution in recent years. Although air quality was at its worst levels in Toronto during the early 1960s, organized environmental interest groups were slow to start pressuring governments to improve air quality management. By the time the environmental movement reached its zenith in the period 1967 to 1970, most pollutants had declined substantially to levels that could no longer be considered significant olfactory irritants. Nevertheless, public concern that air pollution was the number one community problem peaked with media coverage that emphasized problems with air quality. Since the media have not given the same level of attention to improvements in air quality, and overall reporting on air pollution has declined since 1970, it is suggested by Dworkin and Pijawka that the public may see the problem as being less serious since there is less coverage, and yet be entirely unaware of improvements in air quality because these aspects are not so prominently reported.

Experience with the introduction, in Toronto, of an air quality index as a method of informing the public about changes in air quality has been equally dismal. Initial publication of the index in 1970 in local newspapers resulted in a small positive change in perceived importance of air quality. Prominent display of the index on the front page of newspapers helped to focus attention upon air pollution as a major problem, particularly with respect to "First Alert Level Events." However, when the index was moved off

the front page to the weather report section, public attention to the index declined, and most respondents of surveys paid little notice to it.

Nevertheless, Dworkin and Pijawka note that community awareness surveys of the most serious environmental problems in Toronto still rank air pollution as the number one problem over both water and noise pollution. The authors conclude that, in 1978, the population of Toronto was more willing to spend money for an improved environment and was more committed to demanding stronger regulatory control by government in the form of legal action against polluters in order to improve and protect air quality than was the population in the late 1960s.

5. INTERVIEWS WITH ALBERTA'S RESEARCH COMMUNITY

During the course of this study, a total of approximately 40 individuals and/or agencies were interviewed on the telephone to establish their research interest and experience in urban air quality research. Persons contacted were representatives from various levels of government, research establishments, associations, industry, and the academic community. A special questionnaire was used during these interviews to facilitate the documentation of research experience, current activities, and plans for future work related to urban air quality. The original list of persons to be contacted was supplied by RMD; however, during the course of these interviews, additional individuals were identified and contacted.

Following these telephone discussions, criteria were established for the selection of a limited number (12 persons and/or agencies) who would be personally interviewed to solicit more detailed comments on their current activities and future research objectives. The selection criteria used were based primarily on the individual's and/or agency's interest in urban air pollution, and in the case of researchers, on their level of past and current activities. However, the selection process also endeavoured to seek input from representatives of the following groups:

1. consulting firms;
2. research establishments;
3. academic community;
4. Alberta Environment;
5. municipal government; and
6. formal associations.

Many more individuals could have been personally interviewed and would have provided valuable input; however, the time constraints associated with this project precluded this. Therefore, the list of individuals and agencies interviewed (during February 1984) was limited to the following:

1. City of Calgary
   - Western Research and Development
     - Dr. D. Leahey
     - Mr. M. Schroeder
   - INTERA Technologies Ltd.
     - Dr. D. Davison
     - Mr. K. Grandia
   - Air Pollution Control Association, Alberta Chapter
     - Mr. B. Croft
     - Mr. G. Peck
   - The University of Calgary, Atmospheric Physics
     - Dr. A. Harrison
   - The University of Calgary, Kananaskis Research Centre
     - Dr. A. Legge
     - Dr. E. Peake
2. City of Edmonton
   - Alberta Research Council
     - Dr. R. Klemm
   - Edmonton City Planning
     - Ms. E. Wadolna
   - Environment Council of Alberta
     - Mr. D. Buckwald
     - Mr. W. Flook
     - Mr. B. Free
     - Ms. M. Gordon
   - Alberta Environment, Pollution Control Division
     - Mr. J. Lack
     - Mr. W. McDonald
     - Mr. J. Torenby
     - Mr. A. Poulett

Dr. H. Sandhu (RMD) and Mr. R. Angle, Pollution Control Division (PCD) of Alberta Environment provided valuable comments via detailed telephone interviews since it was not possible to conduct personal interviews due to scheduling conflicts.

All individuals interviewed generously provided information on their current activities relating to the understanding of urban air pollution, the results of which are included in the literature review dealing with Alberta research (Section 3 of this report). More importantly, they provided recommendations for future research that might be specifically applicable to the conditions prevailing in Alberta's urban centres. All individual recommendations within the four major study components are summarized in an unedited form in Section 10.1. However, the source of each of these recommendations was not identified. While not all of the recommendations made by every individual are necessarily included in Section 7 of this report, which deals with Alberta's research needs, they did provide the overall framework for identifying these needs.

6. SUMMARY AND CONCLUSIONS

Based upon the studies of urban air quality in Alberta conducted over the past two decades and made available for this review, it was concluded that the cities of Edmonton and Calgary do not rank with the worst urban areas in North America, although at times the levels of pollutants reach concentrations comparable to other large urban areas.

Although not critical at this time, the problem of air quality in Calgary and Edmonton has long been of concern to the citizens of these cities. Repeated public surveys have shown that air pollution is considered to be a major environmental issue, and people are dissatified with the level of response of government agencies to these concerns.

From the available literature on studies in Alberta, it became evident that air quality problems in urban centres exist at several levels. It is generally recognized that vehicular traffic is a primary source of high concentrations of carbon monoxide and lead, and that these pollutants pose a health hazard to pedestrians and office workers in the city core as well as at other locations of heavy traffic congestion. In addition, emissions from automobiles and industry are responsible for the formation of photochemical smog under certain meteorological conditions. The concentrations of total suspended particulates in both Calgary and Edmonton are among the highest levels recorded anywhere in Canada. Furthermore, the presence of toxic substances in the vicinity of industrial activity has been established, though the significance to health effects of observed concentrations is unknown. Moreover, the transmission of some toxic compounds to Edmonton from outside urban areas has been identified, and some evidence exists to indicate that the urban plumes of both Edmonton and Calgary are transported for significant distances downwind.

Although these problems have been identified in Alberta, the quantitative relationships between urban emissions, background atmospheric constituents, atmospheric transport, ambient concentrations, and possible effects or consequences has not been established. Past research in Alberta has at times been characterized as fragmentary, lacking in co-ordination and continuity. More recent studies by Alberta Environment, particularly with respect to atmospheric chemistry, have shown a cohesiveness that has often been lacking in the past. It is extremely important that future research continue to build upon the results of these studies. Furthermore, the interconnection between atmospheric chemistry and other disciplines emphasizes the need to conduct interdisciplinary studies. Implicitly, the assessment and management of ambient air quality require a combination of laboratory studies, supplementary field monitoring programs, and mathematical modelling.

The review of national/international literature has revealed that the pace of research into air quality issues is currently very high, and considerable progress has been achieved in the past decade. However, many issues still remain to be resolved. For instance, the validation and acceptance of air quality models that incorporate both chemical reactions as well as dispersion and transport is being hampered by a lack of adequate data (ie., meteorological, emissions, and ambient air quality). The resources required for validation and implementation of complex models are often beyond the capabilities of any single regulatory agency, while operational and organizational co-ordination of multi-agency programs is proving to be politically difficult. The rapid pace of advancement in the theoretical understanding of air pollution processes in the international research community, inaddition to the high cost of new instrumentation for monitoring and analysis programs, warrants a conservative approach to long-term research commitments.

Because of the central role of modelling in urban air quality research and management, the selection of a model, or models, will to a great extent determine future monitoring data requirements. Therefore, if the implementation of an air quality model, or models, is defined as a general, long-term objective of research in Alberta, then the selection process must consider the ultimate potential applications that the model will be expected to meet. Possible applications might include the following (Demerjian 1976):

1. Research. Gaining an understanding of pollution processes on which to base air pollution abatement strategies.
2. Environmental Legislation. Deciding what standards should be set for emissions from stationary, mobile, or indirect sources in order to meet already agreed-upon ambient standards.
3. Impact Assessment. Predicting the consequences of policy decisions in terms of resulting air quality.
4. Source Identification. Determining which major sources most significantly deteriorate air quality in the modeled region.
5. Monitor Siting. Evaluating optimum site selection for stations in an air monitoring network.
6. Transportation and Land Use Planning. Determining the relative air quality effects of various alternatives for physical development.
7. Episode Control System. Provide real-time simulation and control strategy capabilities for an alert warning system in order to avert episodes of extremely high pollutant concentrations.

A single model is unlikley to be able to meet all potential applications. Some applications can be met by existing models, while others must await further development of complex models. To assist in the selection of models and identification of potential applications specific to conditions in Alberta, it is suggested that

current efforts at exploratory monitoring be continued as short-term research goals. Such monitoring should be directed at the evaluation of ambient air quality at the local or neighbourhood scale of representativeness. Particular emphasis should be placed on monitoring of toxic species in specific locations related to industrial and vehicular emissions.

The exploratory monitoring can best be conducted with mobile monitoring stations equipped with sophisticated air quality monitors and meteorological sensors. At the same time, the monitoring of long-term trends through the existing network of fixed stations should continue unchanged. The eventual selection of an air quality model will determine the need for future expansion or modification of this network.

7. RECOMMENDATIONS FOR URBAN AIR QUALITY RESEARCH IN ALBERTA

The potential for urban air pollution in Alberta has been sufficiently well documented to justify the commitment of significant effort to future research. Furthermore, since the concentration levels of many of the reactive elements are very low, and therefore difficult to measure, the assessment of quantitative relationships in atmospheric transmission will require a combination of laboratory studies, supplementary field monitoring programs, and chemical transformation and dispersion modelling.

These fields of study encompass all components of atmospheric sciences and cannot be segregated into discrete disciplines. The strong interconnections within the fields of chemistry, physics, climatology, meteorology, monitoring, numerical modelling, and consequences of air pollution emphasize the need for a unified interdisciplinary approach to the understanding of urban air pollution.

Therefore, the overall conceptual approach to research on urban air pollution in Alberta will need to encompass the following:

1. Selection and adaptation to Alberta's urban conditions of an existing model, or set of models, developed and validated by other agencies for use as:
   a) a specific research tool for the evaluation of physical and chemical processes; and
   b) a management tool, on a broader scale, for planning and decision making strategies.
2. Definition of chemical constituents that affect atmospheric chemistry either directly as primary or secondary pollutants, or indirectly as catalysts. Both sources and sinks need to be considered at various scales of representativeness.
3. Definition of continuous and episodic monitoring for specific objectives as related to model and/or regulatory requirements.

This conceptual approach can be further divided into broadly defined categories as follows:

1. Long-Term Goals
   a) selection, adaptation and validation of an urban air quality model or models;
   b) modification of monitoring programs, as required, for input to models, validation of models, and long-term regulation; and
   c) limited evaluation of acute and chronic exposure to specific pollutants.
2. Short-Term Goals
   a) measurement of concentrations of a variety of toxic substances through short-term intensive exploratory monitoring;
   b) establishment of the relationship between concentrations measured at the monitoring stations and at street level;
   c) prior to model selection, identification of the unique aspects of prevailing conditions in urban areas in Alberta that may necessitate modification to modelling approximations and/or physical/chemical process assumptions; and
   d) establishment of a computer based inventory of natural and anthropogenic emissions.

7.1 LONG-TERM RESEARCH NEEDS

The following recommendations are listed in order of priority:

Recommendation No. 1: Select, adapt, and validate an urban air quality model or models for use as a research tool and for airshed management.

The rationale for the preceding recommendation is based on the overriding need to conduct urban air quality research utilizing an interdisciplinary approach. The model or models selected will define the links among the various disciplines within the atmospheric sciences and will identify data and research gaps. The selection process ought not to concentrate necessarily on a single model; rather, it should subscribe to the integration of several models at different scales and build on current state-of-the-art knowledge. Models to be considered should include, but not be restricted to, the use of climatological, emissions, airflow, and receptor models, as well as urban diffusion models. Some models are already available and could be implemented at an early stage, while others may require further development and evaluation by other agencies.

Recommendation No. 2: Limit evaluation of acute and chronic exposure to specific pollutants.

In general, the evaluation of health effects on human populations exposed to air pollution is beyond the manpower and resources of the Alberta Government. However, three specific research topics are suggested for consideration by Alberta Environment:

1. Measurement of chronic exposure levels that affect the people working and/or living in areas subjected to elevated pollutant concentrations.
2. Limited evaluation of health effects of some specific pollutants prevalent in Alberta, such as NO_x and H_2S, which may pose health hazards.
3. In the event of a major accidental release to the atmosphere of toxic substances affecting a portion of the population, the Alberta Government should initiate an epidimeological study to document acute effects and monitor long-term chronic effects.

Recommendation No. 3: Modify monitoring programs as required for model input, validation, and long-term regulation.

Due to excessive costs of design and operation of large scale air quality and meteorological monitoring programs, it is recommended that a conservative approach be adopted. Hence, the monitoring needs have been classifed as a long-term goal. The choice of model or models will significantly influence the network design. In the meantime, the current network of fixed monitoring stations should be maintained to provide continuity in long-term trend analysis with the exception of minor modifications as recommended under the short-term goals.

Recommendation No. 4: Adopt analytical techniques developed by other agencies for monitoring exotic pollutants that may be identified as prevalent in urban environments through broad range episodical monitoring.

The emphasis here is to build on existing technology to adopt and certify instrumentation that may be required for the regular monitoring of exotic pollutants. These pollutants could be identified through short-term intensive monitoring as recommended in Section 7.2 (Recommendation No. 3).

7.2 SHORT-TERM RESEARCH NEEDS

The following recommendations are listed in order of priority, with the exception of numbers 6 and 7, which are of equal priority:

Recommendation No. 1: Prepare a data catalogue of historical ambient air quality and meteorological information from previous studies and reports in order to synthesize the general level of knowledge relating meteorological parameters to urban air pollution levels in Alberta.

The catalogue summary should include a description of the type of data, sources, period of record, geographic location, and a classification of data reliability.

Recommendation No. 2: Modify existing air quality monitoring stations to provide:

1. a distinction between inhalable and non-inhalable TSP size fractions;
2. a more detailed breakdown of the organic compounds; and
3. a report on measured values of NO, NO_2, and NO_x.[1]

This recommendation has been clearly identified in most literature reviewed and was expressed by most researchers interviewed.

Recommendation No. 3: Conduct intermittent short-term monitoring using mass spectrometry in order to:

1. identify possible toxic pollutants through broad spectrum analysis and identify prevalent compounds; and
2. determine the chemical composition of particulates (TSP) by size fraction.

---

[1] Although the air monitoring reports of Alberta Environment currently provide summaries of NO_2 and NO_x concentrations, deriving an estimate of NO from these values is not trivial, and many individuals interviewed expressed a desire to have all three constituents reported separately.

This recommendation has been also identified in the literature reviewed and was expressed by many researchers interviewed.

Recommendation No. 4: Establish the relationship between concentrations measured at the monitoring stations and at street level.

The rationale for this recommendation is based on the Alberta, national, and international literature that has identified significant differences between concentrations measured at fixed monitors and street level that have not been statistically quantified. Furthermore, most researchers interviewed have also made this recommendation.

Recommendation No. 5: Establish a computer based inventory of natural and anthropogenic emissions of significant pollutants.

While Alberta Environment is currently updating the inventory of anthropogenic emissions within the urban space, there is a need to define natural sources and levels within and from outside urban areas. Outside contributions should include an accounting of both industrial and natural sources (fugitive dust, forest fires). The computer inventory should be designed to facilitate ongoing changes and revisions based on current information.

Recommendation No. 6: Design a number of integrated studies based on intensive short-term supplementary monitoring; conduct such studies to answer specific questions related to urban air pollution concerns in Alberta. These areas of concern are listed below in approximate order of priority:

1. Define the role of climatological factors (e.g., temperature, radiation, humidity) that influence

chemical transformations in Alberta. In particular, assess the effects of low temperatures and low solar intensity on reaction rates. Deposition rates during frozen precipitation events should also be considered.

2. Examine the role of fine particles in processes such as rain and snow (particularly downwind of urban centres), fog dissipation, ice fog formation, hail suppression, and the alteration of atmospheric conductivity. Little work has been attempted in Alberta on the liquid phase chemistry of pollutants, although it appears that this may be an important removal mechanism (especially in winter). Such studies are intended to supplement national and international research by their application to specific climatic conditions prevailing in Alberta.
3. Examine the role of domestic woodburning emissions on atmospheric chemistry, particularly emissions from widely-used woodburning stoves (incomplete combustion).
4. Examine the chemical behaviour of plumes from point sources. Research should include monitoring of NO, NO_2, O_3, PAN, PPN, and HNO_3 levels as well as aerosol sizing and chemical composition.
5. Examine the sources and sinks of herbicides and pesticides, their chemical transformations, deposition rates, and distribution among the gaseous, liquid, and solid phases.
6. Examine the volatility of chemicals from waste disposal sites and their relative contributions to air pollution.
7. Examine, through monitoring, the relationship between visibility and particle loading.
8. Examine the effects of air pollution on green belts and city parks.

Recommendation No. 7: Identify the unique environmental aspects prevailing in Alberta that influence pollutant transport, dispersion, transformation, and deposition. This recommendation can best be accomplished through the short-term intensive monitoring of meteorological parameters in conjunction with programs under Recommendation No. 6. The following specific suggestions are made in approximate order of priority:

1. Establish a network of surface and low-level wind monitoring stations within Edmonton and/or Calgary in order to provide a data base for analysing urban airflow patterns and to support pollutant monitoring studies. Temperature and relative humidity sensors should be incorporated into this network, although ideally the surface temperature monitoring network should have a finer grid spacing than the wind monitoring network.
2. Conduct a periodic series of integrated short-term monitoring programs using low-altitude tethered balloons, minisondes, and possibly aircraft to obtain vertical profiles of wind speed and direction, vertical shear distribution (particularly during chinooks), temperature, mixing heights, and water vapour content. Analysis should include correlation with regional scale airflow at the 850 mb level and with synoptic climatology. Monitoring of some pollutants such as ozone and its precursors could be accomplished in conjunction with these programs in order to examine specific meteorological conditions that give rise to high air pollution episodes.
3. Conduct a program of continuous acoustic sounder monitoring of inversion heights in Calgary and at a remote location close to the Rocky Mountains in order

to determine the relationship between the effective mixing heights close to the mountains and in the city during chinook phenomena.

4. Conduct a short-term intensive program of monitoring micro-meteorological conditions in the vicinity of prominent topographic features. Specific studies could examine the up- and down-slope wind patterns along an east-west transect in Calgary, and the magnitude of nocturnal drainage flow and katabatic winds in urban valleys.
5. Conduct periodic intensive monitoring programs in order to determine the upwind transport of pollutants from outside sources to urban areas and the transport of the urban plume downwind to rural locations. Monitoring should include the use of both fixed and mobile units and encompass meteorological and air quality sampling.
6. Examine the possibility of using airborne remote sensing techniques to classify the physical characteristics of urban surfaces. Possible techniques could include the use of microwave sensors for surface roughness classification, infrared photography or digital scanning for sensible heat release at night, and MSS scanning for determining surface albedoes. Infrared photography could be useful in providing guidance for establishing monitoring locations for surface temperature networks.
7. Establish solar radiation monitors at one or two locations in either Edmonton or Calgary to provide continuous measurements of visible and UV radiation. Monitoring should include sporadic measurements of direct solar beam radiation using appropriate filters for different wavelengths. Net radiation balance measurements would also be useful; however, the

selection of an appropriate representative site requires careful consideration.

8. Establish a network of precipitation monitoring stations in Edmonton and Calgary, and within a 40 to 50 km radius of each city centre in order to support studies of the liquid phase chemistry of pollutants. Grid density outside urban area could be less than within built-up urban boundaries. At least two stations should be equipped to monitor both wet and dry deposition downwind of urban centres during precipitation events.
9. Conduct a special study in conjunction with item 2 of Recommendation No. 6 to assess the spatial and temporal distribution of cloud cover and fog over urban areas.

7.3 RECOMMENDATIONS FOR RESEARCH IN RESPONSE TO PERCEIVED PUBLIC CONCERNS

During the course of the interviews with representatives from government, industry, and the private and academic communities within Alberta, considerable discussion centred on Alberta's ambient air quality objectives, the ability of the general public to understand the existing air quality index, and the need to consider indoor air pollution. Therefore, specific recommendations regarding these topics were made and are summarized in the following sections.

7.3.1 Ambient Air Quality Objectives

7.3.1.1 Background. Alberta Environment has adopted a combination of the Federal Government's Maximum Desirable Objectives for some pollutants and Maximum Acceptable Objectives for others (where desirable levels are not specified), and has referred to these, within the Clean Air Act, as the Maximum Permissible Concentrations of Air Contaminants in the Ambient Air. In the federal objectives,

the maximum desirable level represents a long-term goal, and provides a basis for an antidegradation policy for unpolluted areas and for the continuing development of control technology. The maximum acceptable level is defined as providing "protection against effects on soil, water, vegetation, materials, visibility, personal comfort, and well-being." When this level is exceeded, action by a regulatory agency is indicated. The maximum tolerable level represents a level beyond which, because of a diminishing margin of safety, action is required to protect the health of the general population.

This three-tier system (desirable, acceptable, tolerable) is not officially used in Alberta and regulatory response to exceedence of guidelines in urban centres is not in place (unless the cause can be attributed to a specific industrial source). On the other hand, the Pollution Control Division enforces strict monitoring of ambient air quality for each industrial facility to ensure that guidelines are met and that corrective action is taken if violations persist. No distinction is made between industry infractions in populated or unpopulated areas.

Laboratory experiments and episodes of high air pollution have established a definite connection between high concentrations of specific pollutants and acute health effects, yet the literature seems to lack a definition of a link between chronic health effects and low levels of pollution. There seems little doubt, however, that air pollution is a contributing factor to the rising incidence of chronic respiratory diseases including emphysema, bronchitis, and asthma. While air pollution episodes are of course alarming, of greater concern may be the long-term effect of much lower levels of air contaminants on those who live and/or work in a continuously polluted atmosphere.

It should be noted that in the case of TSP, it may be difficult to meet current objectives in Alberta, since a large contribution of dust is derived from local agricultural and/or construction activities. Similarly, natural background

concentrations of ozone may at times exceed ambient air quality objectives even in areas far removed from anthropogenic emissions. Therefore, the specific environmental conditions in Alberta dictate the need for a review of existing air quality guidelines. For example, if TSP limits cannot be met due to the contributions from agricultural activities, the limits could be increased providing that certain toxic constituents in particulates (e.g., lead) are within well defined limits and a margin of safety for the protection of public health is maintained.

> Recommendation No. 1: It is recommended that the adequacy of the existing guidelines, specifically as they apply to and are enforced in the urban environment, be critically reviewed.

7.3.2 Air Quality Index

7.3.2.1 Background. The existing air quality index was introduced as a mechanism for informing the public of the general level of air pollution and to provide warnings during air pollution episodes. While every effort was made to devise an index as simple as possible so that it could be understood by the lay public, there are uncertainties, even among the researchers interviewed, as to its meaning and significance. Furthermore, these daily values do not provide a synthesis of seasonal or annual trends for the lay public.

The Pollution Control Division, Alberta Environment, also prepares annual reports summarizing results of the monitoring programs in the cities of Edmonton and Calgary. While these reports are made available to the interested public, they are several years out of date (the latest published report is for 1979) and provide little in the form of trend analysis. This latter criticism is being corrected for future editions, commencing with the report for the year 1982.

Recommendation No. 2: In addition to planned trend analysis, it is recommended that the annual reports include intercity comparisons on a national basis using NAPS data. Furthermore, it is recommended that Alberta Environment investigate additional means of informing the public of the status of urban air quality (e.g., advise city councils in Edmonton and Calgary).

7.3.3 Indoor Air Quality

7.3.3.1 Background. The advent of energy conservation has brought about the need for sealed office buildings, thereby limiting the supply of outside air during cold and hot days. Therefore, office workers will be exposed over a lengthy period (8 h/d) to an atmosphere containing pollutants generated both from within and outside the building envelope. While it may be beyond the mandate of Alberta Environment to provide the manpower and resources in order to fully understand the consequences of indoor air pollution, it may be possible to collaborate with the other provincial and federal governments on joint technical research. Furthermore, there are concerns regarding the lack of applicable guidelines, monitoring, and regulation of indoor air quality.

Recommendation No. 3: While jurisdictional authority concerning indoor air pollution may already be in place, it is recommended that it be reviewed. Furthermore, it is recommended that the monitoring and regulation of indoor air pollution be examined to determine whether or not it is necessary.

8. REFERENCES CITED

Ader, A.W. 1981. Review of the literature and on-going EPA projects comparing portable dosimeters and fixed site monitors as accurate indicators of exposure to carbon monoxide. U.S. Environmental Protection Agency. Report No. EPA-AA-CTAB-PA-81-14.

Alberta Environment. 1974, 1975, 1976, 1977, 1978, 1979. Air monitoring reports, Edmonton. Pollution Control Division, Edmonton, Alberta.

Alberta Environment. 1974, 1975, 1976, 1977, 1978, 1979. Air monitoring reports, Calgary. Pollution Control Division, Edmonton, Alberta.

Alberta Environment. 1978a. Inventory of air pollution sources and emissions in the City of Calgary, 1973. Pollution Control Division, Edmonton, Alberta.

Alberta Environment. 1978b. Inventory of air pollution sources and emissions in the City of Edmonton, 1973. Pollution Control Division, Edmonton, Alberta.

Alberta Environment. 1981. The impact of industrial emissions on the ambient air quality in the Clareview District of Edmonton. Air Quality Control Branch, Pollution Control Division, Edmonton, Alberta.

Alberta Environment. 1982. Industrial sulphur emissions for Alberta 1977-81. Air Quality Control Branch, Pollution Control Division, Edmonton, Alberta.

Angle, R.P. 1974. Pollution potential in Alberta cities. Alberta Environment, Air Quality Control Branch, Edmonton, Alberta.

Angle, R.P. 1981. User considerations in air quality modelling. Proceedings 15th Annual Congress of the Canadian Meteorological and Oceanographic Society, Air Pollution Session. Saskatoon, Saskatchewan. pp. 171-182.

Angle, R.P. 1983. Urban air pollution meteorology in Alberta Environment. Presented at urban air quality workshop, October 17-18; Edmonton, Alberta.

Angle, R.P. and J.E. Torneby. 1975. The coordination of a joint air pollution field study in Edmonton, Alberta. Presented at 1975 annual meeting of PNWIS-APCA. November 19-21; Vancouver, B.C.

Angle R.P., H.S. Sandhu and W.J. Schnitzler. 1978a. A preliminary field study of nitrogen oxides in the exhaust plume from a compressor installation. Presented at the 71st annual meeting of APCA. 1978 June 25-30; Houston, TX.

Angle, R.P., H.S. Sandhu, and W.J. Schnitzler. 1978b. Observed and predicted values of NO_2/NO_x in the exhaust plume from a compressor installation. Alberta Environment, Edmonton, Alberta.

Angle, R.P. and J.U. Godin. 1979. A meteorological station for air quality management. Presented at 1979 annual meeting of PNWIS-APCA. November 7-9; Edmonton, Alberta.

Angle R.P. and J.U. Godin. 1982. Toward an atmospheric boundary layer climatology for central Alberta. Alberta Environment, Air Quality Control Branch, Edmonton.

Anthes, R.A. et al. 1978. Select research group in air pollution meteorology - third progess report. U.S. Environmental Protection Agency. Report no. EPA-600/4-78-049.

Anthes, R.A. and T.T. Warner. 1978. Applications of general meteorological models to air quality research. IN: Air quality meteorology and atmospheric ozone, eds., A.L. Morris and R.C. Barras, American Society for Testing and Materials. ASTM STP 653:304-328.

Ashwell, I.Y. 1968. Studies of the chinook at Calgary: a progress report. The Alberta Geographer 4:45-47.

Basuk, J. and A. Nichols. 1978. An overview of the oxides of nitrogen hazard in Canada. Working paper prep. for the Science Council of Canada.

Bell, R.J. and G.E. Anderson. 1977. Optimal site exposure criteria for SO_2 monitoring. U.S. Environmental Protection Agency. Report no. EPA-450/3-77-013.

Benarie, M.M. 1980. Urban air pollution modelling. Cambridge, MA: MIT Press.

Berry, M.O. 1970. The effects of urban expansion on temperatures in the City of Edmonton, Alberta. Edmonton: University of Alberta, Dept. of Geography. M.Sc. Thesis.

Biggins, P. and R. Harrison. 1979. Characterization and classification of atmospheric sulphates. Journal of the APCA 29(8):838-840.

Blokker, P.C. 1978. Atmospheric sulphates: occurrence, formation, fate and measurement - a critical review. CONCAWE, Den Haag, Report no. 7/78.

Bottenheim, J.W. and O.P. Strausz. 1978. Computer modelling on polluted atmospheres and the conversion of atmospheric sulphur dioxide to sulphuric acid. Prep. for Alberta Environment, Research Secretariat. RS Report 1978/5.

Bottenhein, J.W., S.E. Braslavsky, and O.P. Strausz. 1977. Modeling study of seasonal effect on air pollution at 60°N latitude. Environmental Science and Technology 11:801.

Brinkman, W. and I.Y. Ashwell. 1968. The structure and movement of the chinook in Alberta. Atmosphere 6:1-10.

Budiansky, S. 1980. Dispersion modelling. Environmental Science and Technology 14 (4):370-374.

Campbell, J.E. 1972. The meso-scale circulation induced by the City of Edmonton, Alberta. Edmonton, Alberta: University of Alberta, Dept. of Geography. M.Sc. Thesis.

City of Calgary. 1978. Don't hold your breath: an overview of air pollution in downtown Calgary. City Planning Dept., Downtown and Inner City Plan.

Chipman, M.L. 1977. The effects of sulphur compounds on human health. IN: Sulphur and its inorganic derivatives in the Canadian environment. Associate Committee on Scientific Criteria for Environmental Quality. National Research Council Canada. NRCC Report no. 15015. Ottawa, Ontario.

Cleary, G. 1974. Measurement of air pollution in urban areas: the WHO international air monitoring networks. Proceedings of a Technical Conference on the Observation and Measurement of Atmospheric Pollution (TECOMAP). WMO. Geneva, Switzerland.

Coombes, C.A. and A.W. Harrison. 1982. An automatic all sky scanning radiometer. Canadian Journal of Physics 60(6):919-925.

Daniels, P.A. 1965. The urban heat island and air pollution with application to Edmonton, Alberta. Edmonton: University of Alberta, Dept. of Geography. M.Sc. Thesis.

Das, N.C. and E.S. Howrish. 1980. Determination of volatile organics in ambient air in the vicinity of Celanese Canada Ltd., Edmonton, Alberta. Alberta Environment, Air Analysis and Research Section. Edmonton, Alberta.

Deardorff, J. 1978. Different approaches toward predicting pollutant dispersion in the boundary layer, and their advantages and disadvantages. WMO Symposium on Boundary Layer Physics Applied to Specific Problems of Air Pollution. Geneva, WMO no. 510.

Demerjian, K.L. 1976. Photochemical air quality simulation modelling: current status and future prospects. EPA international conference on photochemical oxidant pollution and its control. 1976 Sept. 12-17; Raleigh, NC.

Demerjian, K.L., J.A. Kerr, and J.G. Calvert. 1974. The mechanism of photochemical smog formation. Advances in Environmental Science and Technology 4 (1).

Dennis, R.L. 1982. Regional air quality policy analysis. IIASA Proceedings Series. Vol. 17: mathematical models for planning and controlling air quality, eds. G. Fronza and P. Melli. Pergamon Press.

Dimitriades, B. 1981. The role of natural organics in photochemical air pollution - issues and research needs. Journal of the APCA 31(3):229-235.

Djurfors, S.G. 1969. Urban air pollution and spatial distribution of temperature. Edmonton: University of Alberta, Dept. of Geography. M.Sc. Thesis.

Dobko, S.L., P.M. Ullman, J.C. Lack, and G.R. Peck. 1971. Measured air pollution levels in Edmonton and Calgary. Annual Meeting of the PNWIS of APCA. Calgary, Alberta: Alberta Environment.

Dworkin, J.M. and K.D. Pijawka. 1981. Air quality and perception: explaining change in Toronto, Ontario. Institute of Environmental Studies, University of Toronto. Pub. no EPR-9. Toronto, Ontario.

Earl, G.O. and P.A. Beauchemin, Jr. 1973a. Inventory of air pollution sources and emissions in the City of Edmonton, 1971. Prepared by Western Research and Development Ltd. for Alberta Environment.

Earl, G.O. and P.A. Beauchemin, Jr. 1973b. Inventory of air pollution sources and emissions in the City of Calgary, 1971. Prep. by Western Research and Development Ltd. for Alberta Environment.

Egan, B.A. 1980. Discussion paper - atmospheric dispersion modelling: a critical review. Contribution to Atmospheric Dispersion Modelling, APCA Reprint Series, eds. H.M. Englund and W.T. Beery.

Eliassen, A. 1982. Applications of meteorological dispersion models. Contribution to WMO Technical Note no. 176, Ch. 5. Geneva, Switzerland.

Environment Canada. 1980. Guidelines for a short-term air quality index. Federal-Provincial Committee on Air Pollution. Ottawa, Ontario.

Environment Canada. 1981a. A nationwide inventory of emissions of air contaminants (1976). Environmental Protection Service, EPS 3-AP-80-1. Ottawa, Ontario.

Environment Canada. 1981b. National air pollution surveillance. Annual summary 1980. Air Pollution Control Directorate. EPS 5-AP-81-13. Ottawa, Ontario.

Environmental Health Directorate. 1982. Nitrogen Dioxide. Health Protection Branch, 83-EHD-86. Ottawa, Ontario.

Environmental Protection Agency. 1975. Guidelines for air quality monitoring network design and instrument siting. OAQPS no. 1.2-012. EPA, Research Triangle Park, NC, p. 75.

Environmental Protection Agency. 1976. Guidelines for air quality monitoring and data reporting under ESECA. OAQPS no. 1.2-034. EPA, Research Triangle Park, NC, p. 25.

Environmental Protection Agency. 1977. Air quality criteria for lead. Office of Research and Development, Report no. EPA-600/8-77-017. Washington, DC.

Environmental Protection Service. 1972a. Standard reference method for the measurement of total oxidants in the atmosphere (iodometric titration). Air Pollution Control Directorate. Report no. EPS 1-AP-72-3.

Environmental Protection Service. 1972b. Standard reference method for the measurement of sulphur dioxide in the atmosphere (West-Gaeke method). Air Pollution Control Directorate. Report no. EPS 1-AP-72-4.

Environmental Protection Service. 1973a. Standard reference method for the measurement of carbon monoxide in the atmosphere (non-dispensive infrared spectrometry). Air Pollution Control Directorate. Report no. EPS 1-AP-73-1.

Environmental Protection Service. 1973b. Standard reference method for the measurement of suspended particulates in the atmosphere (high volume method). Air Pollution Control Directorate. Report no. EPS 1-AP-73-2.

Environmental Protection Service. 1974. Standard reference method for the measurement of nitrogen dioxide in the atmosphere (chemiluminescence method). Air Pollution Control Directorate. Report no. EPS 1-AP-74-2.

Environmental Protection Service. 1976. Ambient air monitoring site selection criteria. Federal-provincial document. EPS, Ottawa, Ont., p. 45.

Environmental Protection Service. 1977. Proposed general rules for the numbers and locations of stations in the NAPS network. NAPS Review Paper.

Environmental Protection Service. 1981a. Standard reference method for the measurement of ozone in the atmosphere (chemiluminescene method). Air Pollution Control Directorate. Report no. EPS 1-AP-73-7 (revised).

Environmental Protection Service. 1981b. The sampling and analysis of airborne sulphate and nitrates: a review of published work and synthesis of available information. Air Pollution Control Directorate. Report no. EPS-5-AP-82-14.

Environmental Protection Service. 1981c. Urban air quality trends in Canada, 1970-1979. Air Pollution Control Directorate. Surveillance Report no. EPS 5-AP-81-14.

Finlayson, B.J. and J.N. Pitts, Jr. 1976. Photochemistry of the polluted troposphere. Science 192, April 9.

Fisheries and Environment Canada. 1976. Criteria for national air quality objectives. Federal-Provincial Committee on Air Pollution, Subcommittee on Air Quality Objectives.

Fronza, G. and P. Melli, eds. 1982. Mathematical models for planning and controlling air quality. Proceedings of an IIASA Workshop. IIASA Proceedings Series, Vol. 17. Pergamon Press.

Georgii, H.-W. and J. Prankrath, eds. 1981. Deposition of atmospheric pollutants. Proceedings of a Colloquium. 1981 November 9-11; Oberurse/Taunus, West Germany.

Geoscience Research Associates Ltd. 1969. Investigation of air pollution in Calgary and Edmonton: April 1, 1968 to March 31, 1969. Report to Department of Public Health, Government of Alberta.

Geoscience Research Associates Ltd. 1970. Investigation of air pollution in Calgary and Edmonton: April 1, 1969 to March 31, 1970. Report to Department of Public Health, Government of Alberta.

Gilmore, T.M. and T.R. Hanna. 1976. The need for representative ambient air CO sampling. Journal of APCA 26:965-967.

Gordon, G.E. 1980. Receptor models. Environmental Science and Technology, 14(7):792-800.

Grandia, K.L. 1981. Feasibility study of airborne hi-vol filter sampling for particulate analyses. Prep. for Alberta Environment, Research Management Division, by INTERA Environmental Consultants Ltd.

Greenhill, S. 1978. Human health effects of hydrogen sulfide. Alberta Environment. pp. 11-12. (Original not seen; information taken from Orford, 1983).

Greenhill, S., E.S.O. Smith, M. Grace, A. Kayani, and B. Juchli. 1975. An evaluation of the health effects of air pollution in Alberta. Prep. for Health and Welfare Canada by the Department of Community Medicine, University of Alberta.

Hage, K.D. 1972. Nocturnal temperatures in Edmonton, Alberta. Journal of Applied Meteorology 11:123-129.

Hage, K.D. 1975. Urban - rural humidity differences. Journal of Applied Meteorology, Vol. 14:1277-1283.

Hage, K.D. 1979. Air pollution study of the North Saskatchewan River Valley in Edmonton, Alberta. Final report on Research Proposal RS77-6. Research Secretariat, Alberta Environment, Alberta.

Hage, K.D. and P. Hopps. 1981. A model for urban area source CO concentrations. Proceedings of the Air Pollution Sessions, Fifteenth Annual Congress of the Canadian Meteorological and Oceanographic Society. Saskatoon, Saskatchewan.

Hage, K.D. and P. Hopps. 1982a. A new air pollution model for Edmonton: Part I. Prepared for Alberta Environment, Research Management Division: RMD Report 82/14.

Hage, K.D. and P. Hopps. 1982b. A new air pollution model for Edmonton: Part II: additional carbon monoxide measurements in the North Saskatchewan River Valley in Edmonton. Prepared for Alberta Environment, Research Management Division. RMD Report 82/10.

Hage, K.D. and R.W. Longley. 1970. Ventilation and mixing in Alberta cities. IN: Man and His Environment, ed. M.A. Ward. Proceedings of the First Banff Conference on Pollution. 1968 May 16-17; Banff, Canada. Pergamon Press.

Hamburg, F.C. 1980. General discussion - atmospheric dispersion modelling: a critical review. Contribution to Atmospheric Dispersion Modelling, APCA Reprint Series, eds. H.M. Englund and W.T. Beery.

Hanna, S.R. 1973. A simple dispersion model for the analysis of chemically reactive pollutants. Atmospheric Environment 7:803-817.

Hanna, S.R. 1982. Review of atmospheric diffusion models for regulatory applications. WMO, Switzerland. Technical Note No. 177.

Harrison, A.W. 1977. An automatic scanning integrating spectronephelometer. Canadian Journal of Physics 55 (16):1399-1406.

Harrison, A.W. 1978. Spectronephelometer studies of aerosols. Canadian Journal of Physics 56 (12):1594-1600.

Harrison, A.W. 1979a. Nephelometer estimates of visual range. Atmospheric Environment 13:645-652.

Harrison, A.W. 1979b. Quiescent boundary layer thickness in aerosol enclosures under convective stirring conditions. Journal of Colloid and Interface Science 69 (3):563-570.

Harrison, A.W. and J. Lant. 1982. Horizon line scanning telephotometry. Canadian Journal of Physics 60 (11).

Harrison, A.W. and C.V. Mathai. 1979. Size distribution of winter continental-mountain aerosols 0.07-1.5 μm. Canadian Journal of Physics 57 (9):1557-1564.

Harrison, A.W. and C.V. Mathai. 1981a. Comparison of telephotometer and nephelometer measurements of atmospheric attenuation and its relationship to aerosol size distribution. Atmospheric Environment 15 (12):2625-2630.

Harrison, A.W. and C.V. Mathai. 1981b. Particulate air pollution and visibility over Calgary. Prep. for Alberta Environment, Research Secretariat. RMD Report 80/2.

Harrison, A.W. and L.B. Murdock. 1982. Perception visual range and sky background. Atmospheric-Ocean 20 (2):116-128.

Harrison, A.W. and R. Pi. 1980. Atmospheric aerosol scattering to mass ratio. Canadian Journal of Physics 58 (4):549-553.

Hicks, R.B. and J. Mathews. 1979. Impact of chinooks on Calgary's air quality: acoustic sounder observations in atmospheric stability. Water, Air, and Soil Pollution 11:159-172.

Hileman, B. 1981. Particulate matter: the inhalable variety. Environmental Science and Technology 15(9):983-986.

Holzworth, G.C. 1967. Mixing depths, wind speeds and air pollution potential for selected locations in the United States. Journal of Applied Meteorology 6:1039-1044.

Hrudey, S.E., B.G. Kratochvil, R.R. Orford, J.W. Markham, and R.K. Shaw. 1983. Scientific Methodology Assessment Committee Report. Prep. for Government of Alberta, Minister of the Environment.

Hwang, C.C. 1978. Air pollution study within an urban valley. Edmonton, Alberta: University of Alberta, Dept. of Geography. M.Sc. Thesis.

Innes, W.B. 1981. Effect of nitrogen oxide emmissions on ozone levels in metropolitan regions. Environmental Science and Technology 15(8).

Isaksen, I. 1982. Chemical transformation in the atmosphere. IN: Troposheric Chemistry and Air Pollution. Geneva. WMO Technical Note no. 176.

Junge, C. 1974. The requirements of the World Meteorological Organization for measurements of atmospheric pollutants. Proceedings of a Technical Conference on the Observation and Measurement of Atmospheric Pollution (TECOMAP). Geneva, WMO. Special Environmental Report no. 3.

Klemm, R.F. 1977a. Nitrogen dioxide studies for Alberta Environment, final report. Alberta Research Council.

Klemm, R.F. 1977b. Sulfur in precipitation: contribution to an Alberta sulfur inventory. Prep. for Alberta Environment, Research Secretariat. Edmonton, Alberta.

Klemm, R.F. and J.M.L. Gray. 1982. A study of the chemical composition of particulate matter and aerosols over Edmonton. Prep. for Research Management Division, Alberta Environment by Alberta Research Council. RMD Report 82/9.

Krahn, H. 1982. Attitudes toward the environment: Edmonton, 1980-1982; Winnipeg 1981. Prep. for Research Management Division, Alberta Environment. Edmonton. RMD Report 79-41.

Krahn, H. 1983. Environmental issues in Alberta: the opinions of Edmonton residents. Prep. for Alberta Environment, Research Management Division. Edmonton. RMD Report 82/17.

Lack, J.C. 1969. Comparison of specific air pollutant levels in Calgary and Edmonton: December 1967 - May 1969. Environmental Health Services Division, Department of Health.

Lack, J.C. 1974. The Alberta Air Quality Index. Presented at the APCA joint meeting of the Ontario and Quebec sections. October 6-7; Ottawa, Ontario.

Lack, J.C. and A.R. Schulz. 1973. Alberta's experience with the development and distribution of an air quality index. Alberta Environment. Edmonton, Alberta.

Lamb, S.I., C. Petrowski, I.R. Kaplan, and B.R.T. Simoneit. 1980. Organic compounds in urban atmospheres: a review of distribution, collection and analysis. Journal of the Air Pollution Control Association 30 (10):1098-1115.

Landsberg, H.E. 1978. Technical comments on: Nkemdirim, L.C. and P. Truch (1978). Atmospheric Environment 12:802-822, 2035.

Leahey, D.M. 1975. An application of a simple advective pollution model to the city of Edmonton. Atmospheric Environment 9.817-823.

Leggat, K.R. 1978. Vertical temperature structure of Calgary's urban heat island. Calgary, Alberta: University of Calgary, Dept. of Georgraphy. 147 pp. M.Sc. Thesis.

Legge, A.H., E.M. Van Zinderen Bakker Jr., E. Peake, and D.C. Lindsay. 1980. The oxides of nitrogen and their interactions in the environment: a review. Prep. for Research Secretariat, Alberta Environment and Canadian Petroleum Association.

Lester, P.F. 1975. A case study of the Alberta chinook. Presented at the Ninth Congress of the Canadian Meteorological Society. May 28-30; Vancouver, B.C.

Lester, P.F. 1976. The chinook of southern Alberta. Presented at the Tenth Congress of the Canadian Meteorological Society. May 25-28; Quebec, P.Q.

Lester, P.F. 1978. A severe chinook windstorm. Submitted to the Conference on Sierra Nevada Meteorology. June 19-21; South Lake Tahoe, CA.

Lettau, H.H. 1970. Physical and meteorological basis for mathematical models of urban diffusion processes. Proceedings of a symposium on multiple-source urban diffusion models, ed. A.C. Stern. U.S. Environmental Protection Agency. Publication No. AP-86.

Longley, R.W. 1967. The frequency of chinook in Alberta. The Alberta Geographer 3:20-22.

Longley, R.W. 1968. The diurnal variation of wind direction at Calgary. Atmosphere 6:23-38.

Longley, R.W. 1969. The diurnal variation of wind direction at Calgary: further comments. Atmosphere 7:1-2 and 35-36.

Longley, R.W. 1973. The mixing height over Edmonton. Edmonton, Alberta: Alberta Environment. Unpublished report.

Ludwig, F.L. 1978. Siting air monitoring stations. Environmental Science and Technology 12(7).

Ludwig, F.L., N.J. Berg, and A.J. Hoffman. 1976. The selection of sites for air pollutant monitoring. Air Pollution Control Association. Preprint 76-11.5; Pittsburg, PA.

MacCready, P.B. Jr. 1978. Applicability of a measurement system: sensor response and representativeness. Air quality meteorology and atmospheric ozone, eds. A.L. Morris and R.C. Barras. American Society for Testing and Materials. ASTM STP 653:74-82.

Maddukuri, C.S., M.B. Danard, and G.A. Davidson. 1978. Some proposed methods to compute winds, temperatures and turbulence parameters for use in urban scale air quality models. Prep. for Boundary Layer Research Division, Atmospheric Environment Service. Downsview, Ontario. Report ARQL 5/78.

Maksylewich, J.W. 1974. Preliminary investigations into lead and cadmium pollution in the city of Edmonton. Edmonton, Alberta: University of Alberta, Dept. of Civil Engineering. M.Sc. Thesis.

Mathai, C.V. and A.W. Harrison. 1980. Estimation of atmospheric aerosol refractive index. Atmospheric Environment 14:1131-1135.

Mathai, C.V. and A.W. Harrison. 1982. Determination of atmospheric aerosol particle size distribution and visibility using a mobile laboratory. Canadian Journal of Physics 60 (8).

Mathai, C.V., A.W. Harrison and J. Mathews. 1980. Aerosol particle size distribution (0.1-1.0 μm) during the chinooks of 1979 over Calgary, Canada. Journal of Applied Meteorology 19(5):515-520.

Mathews, T. and R.B. Hicks. c. 1978. A study of the stability of the atmospheric boundary layer as revealed by an acoustic sounder and its relation to pollution levels in Calgary. Submitted to Alberta Environment, Research Secretariat.

McKee, H.C. 1979. Variability of oxidant problems. Proceedings of a specialty conference on ozone/oxidants: interactions with the total environment. APCA. October 14-17, 1979; Houston, TX.

McRae, G.J., W.R. Goodin, and J.H. Seinfeld. 1982. Mathematical modelling of photochemical air pollution. Pasadena, California: California Institute of Technology, Environmental Quality Laboratory.

Middleton, P., C.S. Kiang, and V.A. Mohnen. 1980. Theoretical estimates of the relative importance of various urban sulfate aerosol production mechanisms. Atmospheric Environment 14: 463-472.

Mirabella, V.A. 1980. Discussion paper - atmospheric dispersion modelling: a critical review. Contribution to Atmospheric Dispersion Modelling, APCA Reprint Series, eds. H.M. Englund and W.T. Beery.

Munn, R.E. 1978. The design of air quality monitoring networks. Institute of Environmental Studies, University of Toronto. Pub. no. EE-7.

Munn, R.E. and J.H. Emslie. 1964. The frequency and intensity of early morning ground inversions at Edmonton 1950-1960. Canada Department of Transport, Meteorological Branch. CIR-4009, TEC-511.

Munn, R.E., J. Tomlain, and R.L. Titus. 1970. A preliminary climatology of ground-based inversions in Canada. Atmosphere 8:52-68.

National Research Council Canada. 1975. Photochemical air pollution: formation, transport and effects. Associate Committee on Scientific Criteria for Environmental Quality. Ottawa, Ont. NRCC Report no. 14096.

National Research Council Canada. 1977. Sulphur and its inorganic derivatives in the Canadian environment. Associate Committee on Scientific Criteria for Environmental Quality. Ottawa, Ont. NRCC Report no. 15015.

National Research Council Canada. 1982. Effects of aerosols on atmospheric processes. Associate Committee on Scientific Criteria for Environmental Quality. Ottawa, Ont. NRCC Report no. 18473.

Natusch, D. and J.R. Wallace. 1974. Urban aerosol toxicity: the influence of particle size. Science 186(4165):695-699.

Nkemdirim, L.C. 1976. Dynamics of an urban temperature field - a case study. Journal of Applied Meteorology 15:818-828.

Nkemdirim, L.C. 1980a. A test of a lapse rate/wind speed model for estimating heat island magnitude in an urban airshed. Journal of Applied Meteorology 19:748-756.

Nkemdirim, L.C. 1980b. Cold air drainage and temperature fields in an urban environment. A case study of topographical influence. Atmospheric Environment 14:375-381.

Nkemdirim, L.C., G.R. Lunn, and R.D. Rowe, 1975. Pollutant concentration and stratification in urban heat island. Water, Air, and Soil Pollution 4:99.

Nkemdirim, L.C. and K. Leggat. 1978. The effects of chinook weather on urban heat islands and air pollution. Water, Air and Soil Pollution 9:53-67.

Nkemdirim, L.C. and P. Truch. 1978. Variability of temperature fields in Calgary, Alberta. Atmospheric Environment 22:809-822.

Oke, T.R. 1981. Boundary layer climates. London: Methuen and Co. Ltd.

Olsson, L.E. 1982. Air quality models, particularly for the mesoscale. IIASA Proceedings Series: Vol. 17: Mathematical models for planning and controlling air quality, eds. G. Fronza and P. Melli. Pergamon Press.

Orford, R.R. 1983. An overview of effects of acid forming gases on human health. Presented at the symposium/workshop on acid forming emissions in Alberta and their ecological effects, 1982 March 11.

Ott, W.R. 1977. Development of criteria for siting air monitoring stations. Journal of the Air Pollution Control Association 27:543-547.

Paproski, D.M. and J.R. Walker. 1974. Air quality in canadian urban areas. Economic Council of Canada. Discussion paper no. 18.

Park, C. 1981. Industrial fog, cloud and precipitation at very low temperatures. Edmonton, Alberta: University of Alberta. Dept. of Geography. M.Sc. Thesis.

Paterson, R.D. 1978. A micrometeorological study of an urban model. Edmonton, Alberta: University of Alberta, Dept. of Geography. M.Sc. Thesis.

Peake, E. 1980. A preliminary study of the chemical composition of particulate matter and aerosols over Calgary. Prep. for Alberta Environment. Research Management Division.

Peake, E. 1983. Peroxyacetyl nitrate in the Calgary atmosphere. Alberta Environment, Research Management Division. RMD Report 83/24.

Peake, E. and H.S. Sandhu. 1983. The formation of ozone and peroxyacetyl nitrate (PAN) in the urban atmospheres of Alberta. Canadian Journal of Chemistry 61:927-935.

Peake, E. and K. Black. 1975. Carcinogenic hydrocarbons as pollutants in the atmosphere of the City of Calgary. Prep. for Alberta Environment by the Environmental Science Centre (Kananaskis), University of Calgary.

Peake, E. and K. Parker. 1979. Carcinogens in the atmosphere of the City of Calgary. Kananaskis Centre for Environmental Research, University of Calgary. Presented at PNWIS-APCA, Edmonton.

Peake, E., M.A. MacLean, and H.S. Sandhu. 1983. Surface ozone and peroxyacetyl nitrate (PAN) observations at rural locations in Alberta (Canada). Journal of the APCA 33 (9).

Peake, E., M.A. MacLean, and H.S. Sandhu. 1985. Total inorganic nitrate (particulate nitrate and nitric acid) observations in Calgary, Alberta. Journal of the Air Pollution Control Association. March issue.

Peters, R.R. and H.S. Sandhu. 1980. Nitrogen oxide emissions for Alberta 1976 to 1979. Research Management Division, Alberta Environment. RMD Report 80/3.

Portelli, R.V. 1977. Mixing heights, wind speeds and ventilation coefficients for Canada. Downsview, Ontario. Atmospheric Environment, Climatological Studies, no. 31.

Ricci, P., H. Inhaber and M. Pinchuk. 1978. Canadian urban air quality, 1971-1975. Atmospheric Environment 12:2369-2375.

Rodhe, H. 1982. Introductory chapter. IN: Tropospheric chemistry and air pollution. Geneva Switzerland. WMO, Technical Note no. 176.

Rolston, J.J. 1964a. A study of air pollution sources and their significance in Calgary, Alberta. Prep. for the Province of Alberta, Dept. of Public Health, Division of Sanitary Engineering.

Rolston, J.J. 1964b. A study of air pollution sources and their significance in Edmonton, Alberta. Prep. for the Province of Alberta, Dept. of Public Health, Division of Sanitary Engineering.

Rossano, A.T. and J.F. Thielke. 1976. The design and operation of air quality surveillance systems. IN: Manual on urban air quality management, eds. M.J. Suess and S.R. Craxford. Copenhagen. WHO Regional Publications, European Series no. 1.

Rudolph, R.C. 1980. A numerical model of pollutant transport in a small urban valley. Edmonton, Alberta. University of Alberta, Dept. of Geography. M.Sc. Thesis.

Sandhu, H.S. 1975. A study of photochemical air pollutants in the urban airsheds of Edmonton and Calgary. Alberta Environment, Research Secretariat. Staff Report no. 1.

Sandhu, H.S. 1976. Oxidant levels in Alberta airsheds. Preprint of presentation to international conference on photochemical oxidant pollution and its control. 1976 September 12-17; Raleigh, NC; 8 pp.

Sandhu, H.S., H.P. Sims, R.A. Hursey, W.R., MacDonald, and B.R. Hammond. 1980. Environmental sulphur research in Alberta: a review. Alberta Environment Research Secretariat. Staff Report no. 4.

Sandhu, H.S. and M. Nyborg. 1978. Alberta sulphur gas research workshop III: technical summary and list of participants. 1977 November 17-18; University of Alberta, Edmonton, Alberta.

Santini, D.J. 1976. Urban design and public exposure to carbon monoxide. Argonne National Laboratory, University of Chicago Center for Urban Studies.

Schroeder, W.H. 1975. Air pollution aspects of odorous substances. A literature survey. Environmental Protection Service. Report EPS 3-AP-75-1.

Sciex™, Inc. 1982. Air quality surveys in Alberta using the TAGA 3000 mobile laboratory. Report to Alberta Environment.

Sexton, K. and H. Westberg. 1981. Nonmethane hydrocarbon composition of urban and rural atmospheres. Presented to 74th Annual Meeting of the APCA. 1981 June 21-26; Philadelphia, PA.

Silverman, F., L.D. Pengelly, S. Mintz, A.T. Kerigan, H.R. Hosein, P. Corey, and C.H. Goldsmith. 1982. Exposure estimates in assessing health effects of air pollution. Environmental Monitoring and Assessment 2:233-245.

Sklarew, R.C. 1980. General discussion - atmospheric dispersion modelling: a critical review. Contribution to Atmospheric Dispersion Modelling, APCA Reprint Series, eds. H.M. Englund and W.T. Beery.

Smith, N.J. 1975. Evaluation of both outdoor and indoor exposure to carbon monoxide and their health significance. Baltimore, Maryland: John Hopkins University. Ph.D. Thesis.

Smith, N.J., C.A. Guenter, and G.W. Hodgson. 1974. Occupational and community exposure to carbon monoxide in Calgary, Alberta. Environmental Sciences Centre (Kananaskis), University of Calgary.

Spengler, J.D. 1980. Discussion paper - atmospheric dispersion modelling: a critical review. Contributions to Atmospheric Dispersion Modelling, APCA Reprint Series, eds. H.M. Englund and W.T. Beery.

Stanley Associates Engineering Ltd. 1973. Survey and assessment of atmospheric odor in the Edmonton area. Prepared for Alberta Environment.

Steenbergen, J.D. 1971. Comparison of urban and rural turbulence statistics at Edmonton, Alberta. Edmonton, Alberta: University of Alberta. Dept. of Geography. M.Sc. Thesis.

Stern, A.C. 1976. The problem before us. IN: Atmospheric pollution, ed. M.M. Benarie. Elsevier, Amsterdam, pp. 1-10.

Stokes, D.W. 1983. Public perceptions of urban air quality. Presented at the urban air quality workshop. 1983 October 17-18; Edmonton, Alberta.

Strong, Lamb, and Nelson Ltd. 1973. Calgary odour survey. Prep. for Province of Alberta, Dept. of Environment.

Strosher, M.T. 1982. Trace organic compounds in the atmosphere near industrial development. Final report submitted to Alberta Environment, Contract No. 82-9109.

Stuart, R. Ambury. 1983. The impact of residential wood burning on urban air quality in Canada. Prep. for Energy, Mines and Resources, Renewable Energy Division. Ottawa, Ontario.

Summers, P.W. 1965. An urban heat island model, its role in our pollution problems with application to Montreal. Paper presented at the 1st Canadian conference on micro-meteorology. 12-14 April; Toronto.

Szepesi, D.J. 1982. Generalizing the concept and factors of air-quality management. IIASA Proceedings Series. vol. 17: Mathematical models for planning and controlling air quality, eds. G. Fronza and P. Melli. Pergamon Press.

Tanner, R.L. and L. Newman. 1976. The analysis of airborne sulfate. A critical review. Journal of Air Pollution Control Association 26:737-747.

Thom, G.C. and W.R. Ott. 1975. Air pollution indices: a compendium and assessment of indices used in the United States and Canada. Prep. for the council on environmental quality and the U.S. Environmental Protection Agency.

Thurston, G.D. 1980. General discussion - atmospheric dispersion modelling: a critical review. Contribution to Atmospheric Dispersion Modelling, APCA Reprint Series, eds. H.M. Englund and W.T. Beery.

Tollefson, E.L. c. 1970a. Air pollution caused by the automobile in Calgary. Calgary, Alberta: University of Calgary, Dept. of Chemical Engineering.

Tollefson, E.L. c. 1970b Atmospheric pollution trends due to motor vehicles in Calgary and Edmonton. University of Calgary. Technical Report no. 3.

Tollefson, E.L. 1972. Sources of air pollutants and future trends in air quality standards. Presented at the CNGPA second quarterly meeting. June 9; Edmonton, Alberta.

Tollefson, E.L. 1973. A review of the Alberta combined air quality index. Calgary, Alberta: University of Calgary, Dept. of Chemical Engineering.

Truch, P. 1977. Spatial and temporal variations of Calgary's surficial temperature field. Calgary, Alberta: University of Calgary, Dept. of Geography. M.Sc. Thesis.

Turner, D.B. 1979. Atmospheric dispersion modelling: a critical review. Atmospheric Dispersion Modelling, APCA Reprint Series, eds. H.M. Englund and W.T. Beery.

Van Gemert, L.J. and G.H. Nettenbreijer, eds. 1977. Compilation of odour threshold values in air and water. National Institute for Water Supply and Central Institute for Nutrition and Food Research TNO. Netherlands.

Van Gysegem, A. 1978. Meteorological observations in urban environments. Royal Meteorological Institute of Belgium. Publications Series B, no. 93.

Venkatram, A. 1978. An examination of box models for air quality simulation. Atmospheric Environment 12:2243-2249.

Vukovich, F.M. c. 1976. Description of a technique for developing an optimum air pollution and meteorological sampling network in urban regions. Proceedings of the International Conference on Environmental Sensing and Assessment. 1975 Sept. 14-19; Las Vegas, NV.

Wada, R.Y. et al. 1979. Application of photochemical models. Volume I: The use of photochemical models in urban ozone studies. Final report. Association of Bay Area Governments. Berkley, CA.

Western Research and Development Ltd. 1971. Sources of emissions inventory for the cities of Edmonton and Calgary - preparations and results. Prep. for Alberta Environment.

Western Research and Development Ltd. 1976a. An application of an air pollution model to the city of Calgary. A summary report prep. for Alberta Environment.

Western Research and Development Ltd. 1976b. An application of an air pollution model to the city of Edmonton. A summary report prep. for Alberta Environment.

Western Research and Development Ltd. 1977a. A preliminary study of the effects of the chinook on the air pollutant levels in Calgary. Prep. for Alberta Environment.

Western Research and Development Ltd. 1977b. Urban area emissions in relation to the assimilative capacity of the atmosphere - Edmonton Region. Prep. for Alberta Environment.

Whelpdale, D.M. 1982. Removal processes. IN: Tropospheric chemistry and air pollution. WMO Technical Note no. 176. Vol. 583, pp. 141.

Wilson, A.L. and T.A. Peters. 1979. Selection of air quality models. Journal of the Technical Councils of ASCE.

Winthrop, S.O. 1973. Air pollution in the urban environment. Environmental Protection Service. Report no. EPS 3-AP-73-6.

World Health Organization. 1972. Air quality criteria and guides for urban air pollutants. Report of a WHO Expert Committee. Geneva.

World Health Organization. 1977. Air monitoring programme: design for urban and industrial areas. WHO, Geneva. Offset Pub. no. 33.

Wright, G.R., S. Jewczyk, J. Onrot, P. Tomlinson, and R.J. Shephard. 1975. Carbon monoxide in the urban atmosphere. Arch. Environ. Health 30:123-129.

Yap, D. 1975. A preliminary investigation of the nocturnal temperature structure above the City of Edmonton, Alberta. Air Resources Branch, Ontario Ministry of Environment. Toronto, Ontario. 25 pp.

Yudcovitch, N. 1967. Factors influencing the temperature variation in Calgary. The Albertan Geographer 3.

9.0 OTHER REFERENCES OF INTEREST TO URBAN AIR QUALITY RESEARCH

The following list of publications compiled by the Research Management Division, Alberta Environment, was provided for this review. Some of the publications were available at the time of the review, but were not cited in the text either because they were superceded by more recent publications, or because the information contained in the reports was too specific to be included in a general review. In many cases, only the reference listing was provided by RMD; the publication itself was not available. The source listing for some references is incomplete. The references are provided only in the interests of having a complete listing of publications relevant to urban air pollution research.

9.1 ALBERTA PUBLICATIONS REVIEWED BUT NOT CITED

Alberta Environment. 1980a. Pincher Creek area. Pollution Control Division. Air quality interim report.

Alberta Environment. 1980b. Air quality monitoring report: Pincher Creek area, March 1, 1980 to May 31, 1980. Air Quality Control Branch, Pollution Control Division. Sessional paper 566/80.

Alberta Environment. 1981. A survey of the ambient air quality in the Pincher Creek area, January 1 to March 24, 1981. Air Quality Control Branch, Pollution Control Division, Edmonton, Alberta.

Angle, R.P. 1975. The utility of stagnation area charts. Alberta Environment, Air Quality Control Branch. Draft Report. 8 pp.

Edmonton Regional Planning Commission. 1976. Pollution and urban growth. Edmonton Region Growth Studies, draft for discussion. Paper no. 3. 58 pp.

Gramms, L.C. 1973. A study of the impact of odours on the City of Calgary. Prep. for Alberta Department of Environment by Strong, Lamb, and Nelson Ltd. 72 pp.

McCoy, E.E. Dr. 1980. Health complaints of families living in the Pincher Creek - Waterton, Alberta area. Report to the Environment Council of Alberta, Sessional paper 568/80.

Reid, R.W., N.C. Das, and W.E. Kortsch. 1977. Analytical study for the determination of hydrogen sulphide in ambient air. Alberta Environment, Pollution Control Division Laboratory.

Stark, R.G. 1963. A study of cases where the minimum temperature at Edmonton occurred before midnight. Canada Department of Transport, Meteorological Branch. Circular no. 3851, TEC 470.

Strosher, M.J. 1981. Environmental selenium levels in the Pincher Creek - Waterton area. Kananaskis Centre for Environmental Research, University of Calgary, Alberta. Final report submitted to Alberta Environment under Contract no. 81-9114.

9.2 NATIONAL/INTERNATIONAL LITERATURE REVIEWED BUT NOT CITED

Ackerman, T.P. 1977. A model of the effect of aerosols on urban climates with particular applications to the Los Angeles basin. Journal of the Atmospheric Sciences 34.

Air Pollution Control Association. 1979. Ozone/oxidants - interactions with the total environment. A specialty conference. March 10-12; 1979. Dallas, Texas.

Air Pollution Control Association. 1979. Ozone/oxidants: interactions with the total environment. A specialty conference. October 14-17; 1979. Houston, Texas.

Allen, R.J. and R.A. Wadden. 1982. Analysis of indoor concentrations of carbon monoxide and ozone in an urban hospital. Environmental Research 27.

Anderson, L.G. 1979. Effects of nighttime chemistry upon the transport of ozone and ozone products. Journal of the Air Pollution Control Association. 29(9).

Antell, M.R. 1979. A model of ozone production in urban plumes. Environment International 2:157-166.

Atwater, M.A. 1971. The radiation budget for polluted layers of the urban environment. Journal of Applied Meteorology 10.

Audurier-Cros, A. 1982. Air pollution in industrial and urban areas and air quality evaluation in 1980, Fos Etang de Berre, France. Energy and Buildings 4(1):15-22.

Barone, J.B., T.A. Cahill, R.A. Eldred, R.G. Flochini, D.J. Shadoan, and T.M. Dietz. 1978. A multivariate statistical analysis of visibility degradation at four California cities. Atmospheric Environment 12:2213-2221.

Barton, S.C. and R.A. Rae. 1978. Photochemical oxidants in Canada. Prep. for Petroleum Association for Conservation of the Canadian Environment, Ottawa, Ontario.

Baudoin, P., A.J. Davies, B.E. Davis, J. Goldbach, E. Holtermann, K.W. Klinsiek, A. Truchot, and G. Whittingham. 1976. Characteristics of urban air pollution: sulphur dioxide and smoke levels in some European cities. Prep. by CONCAWE Special Task Force on Characteristics of Urban Air Pollution, Den Haag.

Benarie, M.M. 1982. Atmospheric pollution. Proceedings of the 15th International Colloquium. May 4-7, 1982; UNESCO Building, Paris, France.

Benson, C.S. 1970. Ice fog. Low temperature air pollution. Corps of Engineers, U.S. Army Cold Regions Research and Engineering Laboratory, Hanover, New Hampshire. Research Report 121.

Bernatzy, A. 1982. The contribution of trees and green spaces to a town climate. Energy and Buildings 5:1-10.

Bowne, N.E. 1974. Diffusion rates. Journal of the Air Pollution Control Association 24(9):832-835.

Bringfelt, B. 1981. Meteorology and air pollution control. Presented at the 5th International Conference on ELMIA air and water and environmental noise protection, 1981 September 21-24; Sweden.

Brown, R.M. and S. Sethuraman. 1977. Trends in atmospheric particulate concentrations at a location in the northeast United States. Presented at 4th joint conference on sensing of environmental pollutants, 1977 November 6-11; New Orleans, Louisiana.

Brunner, F.A. and K.B. Schnelle, Jr. 1974. Air pollution patterns in an urban street canyon. Journal of the Environmental Engineering Division 100 (EE2).

Budiansky, S. 1980. New attention for atmospheric carbon. Environmental Science and Technology 14 (12):1430-1432.

Calder, K.L. 1977. Multiple-source plume models of urban air pollution - their general structure. Atmospheric Environment 11:403-414.

Carlson, R.F. and J. Fox. 1976. An atmospheric carbon monoxide transport model for Fairbanks, Alaska. Institute of Water Resources, University of Alaska, Fairbanks. Report no. IWR-75.

Cautreels, W. and K. Van Cauwenberghe. 1977. Comparison between the organic fraction of suspended matter at a background and an urban station. The Science of the Total Environment 8:79-88.

Chang, T.Y. 1982. Analysis of an O_3 episode using a modified one-dimensional trajectory model. Presented at the 75th Annual Meeting of the Air Pollution Control Association. 1982 June 20-25; New Orleans, Louisiana.

Chang, T.Y., J.M. Norbeck, and B. Weinstock. 1979. An estimate of the NO_x removal rate in an urban atmosphere. Environmental Science and Technology 13(12).

Ching, J.K.S., J.F. Clarke, and J.M. Godowitch. 1983. Modulation of heat flux by different scales of advection in an urban environment. Office of Research and Development, U.S. Environmental Protection Agency. Research Triangle Park, NC. 22 pp.

Chu, K.J. and J.H. Seinfeld. 1975. Formulation and initial application for a dynamic model for urban aerosols. Atmospheric Environment 9:375-402.

Cole, H.S. and J.E. Summerhays. A review of techniques available for estimating short-term NO_2 concentrations. Journal of the Air Pollution Control Association 12(8):812-818.

Congress of the United States. 1982. The regional implications of transported air pollutants: an assessment of acidic deposition and ozone. Interim Draft, Office of Technology Assessment. Washington, DC.

Conrads, L.A. and J.C.H. van der Hage. 1971. A new method of air-temperature measurement in urban climatological studies. Atmospheric Environment 5:629-635.

Daly, N.J. 1979. Use of frequency distributions of potential ozone in evaluating oxidant controls. Environmental Science and Technology 13 (11).

Davis, M.L. and J.E. Pearson. 1970. Modelling urban atmospheric temperature profiles. Atmospheric Environment 4:277-288.

De Heurtley, G.L. 1979. Methodology for the research of air pollution in urban areas. Presented at the international conference on air pollution. 1979 October 22-25; Pretoria (CSIR).

Denison, P.J., B.A. Power, and P.W. Summers. 1960. Analyses of air pollution levels in Montreal related to meteorological variables. Presented at the Royal Meteorological Society Meeting, 1960 June 8; Kingston, Ontario.

Derr, V.E. 1977. Lidar techniques for analyzing and tracing particulate pollutants from energy production. Presented at the EPA Energy and Environment II Conference. 1977 June 6-7; Washington, DC.

Djurfors, S. 1968. An urban air pollution model. The Albertan Geographer 4:65-68.

Doan, M.H. and C. East. 1977. A proposed air quality index for urban areas. Water, Air, and Soil Pollution 8:441-451.

Eagleman, J.R. 1974. A comparison of urban climatic modifications in three cities. Atmospheric Environment 8:1131-1142.

Ellsaesser, H.W. 1978. Air pollution: a different view. Water, Air, and Soil Pollution 11:115-127.

Elsom, D.M. and T.J. Chandler. 1978. Meteorological controls upon ground level concentrations of smoke and sulphur dioxide in two urban areas of the United Kingdom. Atmospheric Environment 12:1543-1554.

Environmental Protection Agency. 1975. Joint strategies for urban transportation, air quality and energy conservation. Federal Energy Administration and U.S. Department of Transportation. Available through NTIS no. PB 244 473.

Environmental Protection Agency. 1982. Air quality criteria for oxides of nitrogen. Report no. EPA-600/8-82-026, Research Triangle Park, NC.

Esmen, N.A. and M. Corn. 1971. Residence time of particles in urban air. Atmospheric Environment 5:571-578.

Evendijk, J.E. 1980. Issuing alerts to reduce the effects of air pollution episodes in the Netherlands. Land and Water International.

Farrow, L.A., T.E. Graedel, and T.A. Weber. 1974. The effect of aerosols on the free radical chemistry of the lower atmosphere. Presented at the symposium on removal of trace contaminants from the air, 168th meeting of American Chemical Society. 1974 September 10-11.

Fezer, F. 1982. The influence of building and location on the climate of settlements. Energy and Buildings 4:91-97.

Franson, M.A.H., R.T. Franson, and A.R. Lucas. 1982. Environmental standards. A comparative study of Canadian standards, standard setting processes and enforcement. Prep. for the Environment Council of Alberta.

Grosjean, D., K. Van Cauwenberghe, J.P. Schmid, P.E. Kelley, and J.N. Pitts, Jr. 1978. Identification of C_3-C_{10} aliphatic dicarboxylic acids in airborne particulate matter. Environmental Science and Technology 12(3).

Grosjean, D. 1982. Formaldehyde and other carbonyls in Los Angeles ambient air. Environmental Science and Technology 16(5).

Hanst, P.L. and B.W. Gay, Jr. 1977. Photochemical reactions among formaldehyde, chlorine and nitrogen dioxide in air. Environmental Science and Technology 11(12).

Heidorn, K.C. 1978. Air pollution incidents and wind variability in southern Ontario. Atmospheric Environment 12:2251-2257.

Henderson-Sellers, B. 1980. The behaviour of marginally buoyant plumes in an urban environment. Ecological Modelling 9:43-56.

Henry, R.C. and G.M. Hidy. 1979. Multivariate analysis of particulate sulfate and other air quality variables by principal components - Part I. Annual data from Los Angeles and New York. Atmospheric Environment 13:1581-1596.

Hidy, G.M. 1973. Urban aerosols and inadvertent weather modification. Proceedings of a workshop on inadvertent weather modification. 1973 August 13-31; Logan, Utah.

Hitchcock, D.R. 1976. Atmospheric sulfates from biological sources. Journal of the Air Pollution Control Association 26(3).

Horbert, M. and A. Kirchgeorg. 1982. Climatic and air-hygenic aspects in the planning of inner-city open spaces: Berlin Grosser Tiergarten. Energy and Buildings 5:11-22.

Hov, O, I.S.A. Isaksen, and E. Hesstvedt. 1978. Diurnal variations of ozone and other pollutants in an urban area. Atmospheric Environment 12:2469-2479.

Huffman, G.D., G.W. Haering, R.C. Bourke, P.P. Cook, and M.P. Sillars. 1976. Ozone observations in and around a midwestern metropolitan area. Presented at the EPA international conference on photochemical oxidant pollution and its control. 1976 September 12-17; Raleigh, NC.

Isaksen, I.S.A., O. Hov, and E. Hesstvedt. 1978. Ozone generation over rural areas. Environmental Science and Technology 12(12):1279-1284.

Ivanyi, Z. and I. Mersich. 1982. Simulation of the urban air pollution based on a numerical UBL model. Atmospheric Environment 16(8):1835-1849.

Johnson, D.L. 1983. A particle class balance receptor model for aerosol apportionment in Syracuse, N.Y. Prep. for the Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC. 17 pp.

Jones, K.H. 1978. CEQ projections of ozone air quality in 1980. Prep. by the Council on Environmental Quality. Washington, DC.

Katz, D., T. Sakunna, and A. Ho. 1978. Chromatographic and spectral analysis of polynuclear aromatic hydrocarbons - quantitative distribution in air of Ontario cities. Environmental Science and Technology 12(8).

Kauper, E.K and B.L. Niemann. 1976. Transport of ozone by upper-level land breeze - an example of a city's polluted wake upwind from its center. Presented at the EPA international conference on photochemical oxidant pollution and its control. 1976 September 12-17; Raleigh, NC.

Kellie, A.R. 1972. Low level atmospheric structure over Calgary in pre-chinook conditions. Edmonton, Alberta: University of Alberta, Dept. of Geography. M.Sc. Thesis.

Kiyoura, R. 1977. Comparison and evaluation of several nitrogen dioxide air quality standards. Journal of the Air Pollution Control Association 27(6).

Kniel, U. 1982. Conserving energy by improving the quality of the air purifying and air conditioning systems. NTIS, Springfield, Virginia. Report no. N83-10651/8.

Kneip, T.J. and P.J. Lioy. 1980. Aerosols: anthropogenic and natural, sources and transport. Annals of the New York Academy of Science Vol. 338.

Koch, R.C. and S.D. Thayer. 1971. Validation and sensitivity analysis of the Gaussian plume multiple-source urban diffusion model. Perp. for Division of Meteorology, U.S. Environmental Protection Agency. GEOMET Report no. EF-60.

Kowalczyk, J.F. and W.T. Greene. 1981. New Techniques for identifying ambient air impacts from residential wood heating. Oregon Department of Environmental Quality. Portland, Oregon.

Krouse, H.R. and J.W. Case. 1984. Design, development and field testing of a mobile nine unit high volume air sampler array. Prep. for Alberta Environment, Research Management Division. Edmonton, Alberta.

Kuttler, W. 1982. The role of evergreen vegetation in industrial agglomeration areas. Energy and Buildings 5:23-30.

Lack, J.C. 1975. Air quality index report as a base for developing a national index. Presented at the Canadian Council of Resource and Environment Ministers Eighteenth Plenary Session and Fourteenth Annual General Meeting, 1975 June 12-13; Edmonton, Alberta.

Laird, A.R., P. Middleton, and R.W. Miksad. 1983. A mechanistic model to study ozone production in urban areas. Journal of Environmental Science and Health A18(3):327-333.

Lamb, D.V., F.I. Badgley, and A.T. Rossano, Jr. 1973. A critical review of mathematical diffusion modelling techniques for air quality with relation to motor vehicle transportation. Prep. for the Washington State Highway Commission, Department of Highways.

Lamb, R.G. 1971. Numerical modeling of urban air pollution. Los Angeles, California: University of California. Ph.D. Thesis.

Leaderer, B.P. 1978 Summary of the New York summer aerosol study (NYSAS). Journal of Air Pollution Control Association 28(4).

Lebowitz, M.D., G. Corman, C.J. Holberg, R. Dodge, and M.K. O'Rourke. 1983. Gas stove usage, CO and TSP, and respiratory effects. Prep. for Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC. 16 pp.

Leslie, L.M. and R.K. Smith. 1974. A numerical study of katabatic winds and their effect on pollutant dispersal in urban areas. Presented at the Fifth Australasian conference on hydraulics and fluid mechanics. 1974 December 9-13; University of Canterbury, Christchurch, New Zealand.

Lioy, P.J., P.J. Samson, R.L. Tanner, B.P. Leaderer, T. Minnich, and W. Lyons. 1980. The distribution and transport of sulfate "species" in the New York metropolitan area during the 1977 summer aerosol study. Atmospheric Environment 14:1391-1407.

Ludwig, F.L. 1979. Vertical profiles of photochemical pollutants in the vicinity of several urban areas. Presented at the 4th symposium on turbulence, diffusion and air pollution of the American Meteorological Society. January 15-18; Reno, Nevada.

Marier, P. and H.P. Dibbs. 1974. Particulates as air pollutants: an introduction to their origin and control. Prep. by the Engineering Division, Technology Development Branch, Air Pollution Control Directorate. Report APCD 74-4.

McCartney, E.J. 1976. Optics of the atmosphere: scattering by molecules and particles. John Wiley and Sons.

McDougal, D.S. and G.L. Gregory. 1980 Measurements of urban plume pollutants up to 100 km. downwind. Proceedings of the symposium on intermediate range atmospheric transport processes and technology assessment. 1980 Oct. 1-3; Gattinburg, Tennessee.

Meisel, W.S. 1976. Empirical techniques for analyzing air quality and meteorological data. Part I. The role of empirical methods in air quality and meteorological analyses. U.S. Environmental Protection Agency. Report no. EPA-600/4-76-029a.

Meisel, W.S., M.D. Teener, and K.L. Calder. 1976. Empirical techniques for analyzing air quality and meteorological data. Part II. Feasibility study of a source-oriented empirical air quality simulation model. U.S. Environmental Protection Agency. Report no. EPA-600/4-76-029b.

Moon, A.E. and F.L. Ludwig. 1973. Predicting motor vehicle air pollution concentrations from highway network analysis. Standford Research Institute. Highway Research Record No. 465.

Munn, R.E. 1981. The design of air quality monitoring networks. London: MacMillan Publishers. 109 pp.

Murray, W.A. 1980. Survey of meteorological emission regulation systems. Prep. for Alberta Quality Control Branch, Pollution Control Division, Alberta Environment by Promet Environmental Group Ltd. Calgary, Alberta.

Nicholson, S.E. 1975. A pollution model for street-level air. Atmospheric Environment 9:19-31.

North Atlantic Treaty Organization. 1973. Air quality criteria for nitrogen oxides. Report by the Expert Panel on Air Quality Criteria, Committee on the Challenges of Modern Society.

Oke, T.R. 1980. Climatic impacts of urbanization. Proceedings of an international workshop on interactions of energy and climate, 1980 March 3-6; Muenster, Germany.

Orleans, M. and G.F. White. 1974. Carbon monoxide and the people of Denver. Institute of Behavioural Science, University of Colorado. Boulder, Colorado.

Pandolfo, J.P. et al. 1971. Prediction by numerical models of transport and diffusion in an urban boundary layer - Volume I. Center for the Environment and Man, Incorporated. Hartford, Connecticut. (Available from NTIS, Report no. PB 206 939)

Parker, G.B., J.G. Droppo, and P.C. Owczarski. 1982. Predicting indoor air pollution levels. Prep. for the U.S. Department of Energy by Pacific Northwest Laboratory. Richland, Washington.

Peterson, J.T. and E.C. Flowers. 1974. Urban-rural solar radiation and aerosol measurements in St. Louis and Los Angeles. Presented at the symposium on atmospheric diffusion and air pollution. 1974 September 9-13; Santa Barbara, California.

Peterson, T.W. and J.H. Seinfeld. 1977. Mathematical model for transport, interconversion and removal of gaseous and particulate air pollutants - application to the urban plume. Atmospheric Environment 11:1171-1184.

Pierce, R.C. and M. Katz. 1975. Dependency of polynuclear aromatic hydrocarbon content on size distribution of atmospheric aerosols. Envoronmental Science and Technology 9(4).

Popov, V.A., L.N. Chernykh, and E.V. Pechennikova. 1980. Ozone content of a city atmosphere in relation to meteorological conditions. Soviet Meteorology and Hydrology 2:105-108.

Sandia National Laboratories. 1982. Indoor air quality handbook for designers, builders and users of energy efficient residences. Prep. for the United States Department of Energy.

Santini, D.J. 1976. Air quality and centre city residential development. Argonne National Laboratory, Energy and Environmental Systems Division, University of Chicago.

Schiavone, J.A. and T.E. Graedel. 1980. 2-D studies of the kinetic photochemistry of the urban troposphere. I. Air stagnation conditions. Atmospheric Environment 15:163-176.

Scupholme, P.L., E.C. Cadron, G.F. Cutolo, J. Goldbach, A. Truchot, C.M. Verheul and P. van der Wee. 1977. The relative contribution of industrial and domestic emissions to SO_2 urban pollution. Prep. by CONCAWE Special Task Force on Urban Emission/Immission Relationships, Den Haag.

Sharma, V. and L.O. Myrup. 1975. Diffusion from a line source in an urban atmosphere. Atmospheric Environment 9:907-922.

Sheih, C.M. 1977. Mathematical modeling of a particulate thermal coagulation and transport downstream of an urban area source. Atmospheric Environment 11:1185-1190.

Simmons, W.R., J.W. Wescott, and F.F. Hall, Jr. 1971. Acoustic echo sounding as related to air pollution in urban environments. NOAA. Technical Report ERL 216-WPL 17.

Singh, H.B., J.R. Martinez, D.G. Hendry, R.J. Jaffe, and W.B. Johnson. 1981. Assessment of the oxidant-forming potential of light saturated hydrocarbons in the atmosphere. Environmental Science and Technology 15(1).

Singh, H.B., L. Salas, H. Shigeishi, and A. Crawford. 1977. Urban - nonurban relationships of halocarbons, SF_6, N_2O and other atmospheric trace constituents. Atmospheric Environment 11:819-828.

Skibin, D. 1975. Siting of industrial zones near cities. Atmospheric Environment 9:543-547.

Small, K.A. 1975. Estimating the air pollution costs of transportation modes. Institute of Urban and Regional Development, University of California, Berkeley. Working Paper no. 261.

Spicer, C.W., P.R. Sticksel, G.M. Sverdrup, A.J. Alkezweeny, and W.E. Davis. 1982. Ozone and NO_x plumes from cities in the northeast corridor. Presented at the 75th Annual Meeting of the Air Pollution Control Association. 1982 June 20-25; New Orleans, Louisiana.

Steinberger, E.H. and E. Ganor. 1980. High ozone concentrations at night in Jerusualem and Tel-Aviv. Atmospheric Environment 14:221-225.

Sterling, T.D. and D.M. Kobayashi. 1977. Exposure to pollutants in enclosed "living spaces." Environmental Research 13:1-35.

Stern, A.C. 1970. Proceedings of symposium on multiple-source urban diffusion models. Prep. by U.S. Environmental Protection Agency, Research Triangle Park, NC.

Stockburger, L., III, B.K.T. Sie, and J. Heicklen. 1976. The inhibition of photochemical smog. V. Products of the diethylgydroxylamine inhibited reaction. The Science of the Total Environment 5:201-222.

Suess, M.J. and S.R. Craxford. 1976. Manual on urban air quality management. WHO Regional Publications European Series no. 1.

Summer, W. 1971. Odour pollution of air: causes and control. Cleveland, Ohio: International Scientific Series, CRC Press.

The Subcommittee on Air Quality Objectives. 1976. Criteria for national air quality objectives: sulphur dioxide, suspended particulates, carbon monoxide, oxidants (ozone) and nitrogen dioxide. Reports to the Federal-Provincial Committee on Air Pollution (1971 and 1973).

Tuesday, C.E. 1971. Chemical reactions in urban atmospheres. Proceedings of the symposium held at General Motors Research Laboratories. 1969; Warren, Michigan.

Turner, W.A. and C.J. Gregory. 1980. Meteorological impacts on urban sulfate levels. Journal of Environmental Engineering Division.

Uboegbulam, T.C. and J.A. Davies. 1983. Turbidity in Eastern Canada. Journal of Climate and Applied Meteorology 22:1384.

United Nations Economic Commission. 1979. Fine particulate pollution. Prep. for the United Nations. Pergamon Press.

Venkatram, A. 1978. On setting air quality criteria. Water, Air, and Soil Pollution 10:441-449.

Vicars, M. 1982. Urban air quality. The air we breathe in our cities - how healthy is it? Environment Views May/June 1982.

Viskanta, R., T.L. Weirich, and R.A. Daniel. 1978. Effects of pollutant and heat emissions on temperature in an urban area. Presented at AIAA/ASME thermophysical and heat transfer conference. 1978 May 24-26; Palo Alto, California.

Wadden, R.A., E.D. Ross, and J.E. Quon. 1979. Characterization of ozone episodes in urban air. Journal of the Environmental Engineering Division. August 1979.

Wakelyn, N.T. and G.L. Gregory. 1980. Comparison of measured ozone in southeastern Virginia with computer predictions from a photochemical model. Environmental Science and Technology 14(8):1006.

Winer, A.M., G.M. Breuer, W.P.L. Carter, K.R. Darnall, and J.N. Pitts, Jr. 1979. Effects of ultraviolet spectral distribution on the photochemistry of simulated polluted atmospheres. Atmospheric Environment 13:989-998.

World Meteorological Organization. 1968. Urban climates. Proceedings of the symposium on urban climates and buildings climatology, jointly organized by the World Health Organization and WMO. October 1968; Brussels, Belgium. (Volume 1) Technical Note no. 108.

Yamasnita, S. 1974. A comparative study of turbidity in an urban and a rural environment at Toronto. Atmospheric Environment 8:507-518.

9.3 AVAILABLE ON MICROFICHE

Alkezweeny, A.J. 1976. Growth of aerosol in an urban plume. 19 pp.

Allwine, K.J. and P.C. Owczarski. 1982. Computing transient indoor air quality. Prep. by Pacific Northwest Laboratory. Richland, WA. 7 pp.

Ando, J. 1983. NO_x abatement for stationary sources in Japan. Tokyo, Japan: Chuo University. Final report, January 1981 - January 1983. 524 pp.

Ball, R.J. et al. 1977. Optimum site exposure criteria for SO_2 monitoring. Prep. for U.S. Environmental Protection Agency by Centre for the Environment and Man, Inc. Hartford, CT. Report no. EPA/450/3-77/013.

Brewer, D.A. et al. 1981. A diagnostic model for studying daytime urban air quality trends. Prep. by NASA, Report no. NASA TP 1843.

Connell, P.S. and D.J. Wuebbles. 1983. Summary of photochemical and radiative data used in the LLNL one-dimensional transport-kinetics model. Prep. by Lawrence Livermore National Laboratory, CA. 43 pp.

Dodd, J.K. 1979. Determination of surface characteristics and energy budget over an urban rural area using satellite data and a boundary layer model. Pennsylvania State University. 96 pp. MSc. Thesis.

Draxler, R. 1979. A summary of recent atmospheric diffusion experiments. National Oceanic and Atmospheric Administration, Silver Spring, MO.

Dudney, C.S. and P.J. Walsh. 1981. Report of ad hoc task force on indoor air pollution. 245 pp.

Environmental Protection Agency. 1978. Altitude as a factor in air pollution. U.S. Environmental Protection Agency, Research Triangle Park, NC. Report no. EPA/600/9-78-015.

Environmental Protection Agency. 1980. Guidance on monitoring upwind of urban areas for determining transport of ozone and its precursors. Monitoring and Data Analysis Division, Research Triangle Park, NC. 23 pp.

Environmental Protection Agency. 1983. Carbon monoxide concentrations in four U.S. cities during the winter of 1981. Environmental Monitoring Systems Laboratory, Research Triangle Park, NC. Report No. EPA/600/4-83-025. 75 pp.

Gammage, R.B. and B.E. Hingerty. 1983. Temporal fluctuations of formaldehyde levels inside residences. 10 pp.

Gatz, D.F. et al. 1983. Characterization of urban and rural inhalable particulates. Illinois State Water Survey Division. 117 pp.

Gipson, G.L. 1982. Comparison of three ozone models: urban airshed, city-specific EKMA and proportional rollback. Final report. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. Report no. EPA-450-4-002. 62 pp.

Gipson, G.L. et al. 1981. Guidelines for use of city-specific EKMA in preparing ozone sips. Final report. U.S. Environmental Protection Agency, Office of Air Quality Planning and Standards, Research Triangle Park, NC. Report No. EPA-450/4-80-027. 144 pp.

Hardy, K.A. 1980. Aerosol source characterization study in St. Louis, trace element analysis. Prep. for U.S. Environmental Protection Agency by Florida International University, Miami. Department of Physical Sciences. Report No. EPA/600/7-80-025. 199 pp.

Harris, F.S., Jr. 1976. Aerosol studies final report, 1 Nov 1972-30 Oct 1975. Prep. by Old Dominion University Research Foundation. 7 pp.

Hawthorne, A.R. and R.B. Gammage. 1983. Preliminary results of a forty home indoor air pollutant monitoring study. 12 pp.

Hillyer, M.S. 1981. Evaluating simple oxidant prediction methods using complex photochemical models: cluster analysis applied to urban ozone characteristics. Prep. for U.S. Environmental Protection Agency, by Systems Applications, Inc., San Rafael, CA. Report No. EPA-600/3-82-041. 117 pp.

Holmbom, A. et al 1982. A mathematical model of the urban boundary layer. 48 pp.

Horie, Y. et al. 1979. Weekend/weekday differences in oxidants and their precursors. Prep. for U.S. Environmental Protection Agency by Technology Service Corp., Santa Monica, CA. Report no. EPA/450/4-79/013.

Langan, L. et al. 1980. Cross-country urban and rural measurements of NO_x and SO_2. Final report. Prep. for U.S. Environmental Protection Agency by Environmental Measurements, Inc., San Francisco, CA. Report no. EPA-600/2-80/023. 75 pp.

Lipschultz R.D. et al. 1981. Infiltration and indoor air quality in energy efficient houses in Eugene, Oregon. 50 pp.

Mammarella, L. 1970. Relation between urban micrometeorology and atmospheric pollution over cities. 30 pp.

Martinez, J.R. et al. 1979. Survey of the role of NO_x in nonurban ozone formation. Prep. for U.S. Environmental Protection Agency by SRI International, Menlo Park, CA. Report no. EPA-450-4-79-035.

Martinez, J.R. et al. 1983. Evaluation of the empirical kinetic modeling approach (EKMA). Prep. for U.S. Environmental Protection Agency by SRI International, Menlo Park, CA. Report No. EPA-600/3-83-003. 133 pp.

Meyer, E.L. et al. 1980. Technical basis for developing control strategies for high ambient concentrations of nitrogen dioxide. Office of Air Quality Planning and Standards, U.S. Environmental Protection Agency, Research Triangle Park, NC. Report no. EPA-450/4-81-031E. 43 pp.

Miller, D.F. et al. 1975. Haze formation: its nature and origin. Battelle Columbus Lake, OH. 103 pp.

Muggli, R.Z. et al. 1983. Comparison of inhalable particulate and total suspended particulate. McCrone (Walter C.) Associates, Inc., Chicago, IL. 145 pp.

Myrup, L.D. et al. 1976. A consistent scheme for estimating diffusivities to be used in air quality models. California State Department of Transportation. Sacramento, CA.

North Atlantic Treaty Organization. 1976. Air pollution. Appendix G. Mathematical model for urban diffusion of carbon monoxide from motor vehicles. NATO Committee on the challenges of modern society. Brussels, Belgium. 82 pp.

Ott, W. et al. 1967. Calculating future carbon monoxide emissions and concentrations from urban traffic data. National Air Pollution Control Administration. Durham, NC.

Owczarski, P.C. and G.B. Parker. 1983. Computing transient exposure to indoor pollutants. 13 pp.

Pace, T.G. 1978. An approach for the preliminary assessment of TSP concentrations. U.S. Environmental Protection Agency, Research Triangle Park, NC. Report no. EPA/450/2-78/016.

Parker, G.B., P.C. Owczarski, and W.F. Sandusky. 1982. Residential weatherization - indoor air pollution. Pacific Northwest Laboratory. Richland, WA. 8 pp.

Paul, R.A. 1979. The impact of future diesel emissions on the air quality of large cities. Prep. for U.S. Environmental Protection Agency by Pedco-Environmental, Inc. Durham, NC. Report No. EPA-450-5-79-005.

Pedco-Environmental, Inc. 1979. TSP source inventory around monitoring sites in selected urban areas, St. Louis. Pedco-Environmental, Inc. Kansas City, MO. 183 pp.

Peterson, J.T. et al. 1979. Urban-rural solar radiation measurements in St. Louis, Missouri. National Oceanic and Atmospheric Administration. Silver Spring, MO.

Rao, S.T. 1978. Dispersion of pollutants near highways - experimental design and data acquistion procedures. Prep. by New York State Department of Environmental Conservation. Albany, NY. Report no. EPA/600/4-78/037.

Reynolds, S.D. et al. 1973. Urban air shed photochemical simulation model study. Volume I. Development and evaluation. Systems Applications, Inc. Beverly Hills, CA. 151 pp.

Schewe, G.J. 1975. A climatology of inversions. Fort Collins, Colorado: Colorado State University, Department of Atmospheric Science. 118 pp.

Spicer, C.W. et al. 1979. Investigations of nitrogen oxides within the plume of an isolated city. Battelle Columbus Laboratories, OH.

Traynor, G.W., M.G. Apte, J.R. Girman, and C.D. Hollowell. 1981. Indoor air pollution from domestic combustion appliances. Lawrence Berkeley Laboratory, CA. 14 pp.

Vaupel, J.W. 1983. Analytical perspectives on setting environmental standards. Final report. Prep. for U.S. Environmental Protection Agency by Duke University. Durham, NC. Report no. EPA-450/5-83-002. 123 pp.

Viskanta, R. et al. 1979. Effects of pollutants and urban parameters on atmospheric dispersion and temperature. Prep. for U.S. Environmental Protection Agency by Purdue University, Lafayette, IN: School of Mechanical Engineering. Report no. EPA/600/4-79/012.

Watson, J.G. et al. 1981. Analysis of inhalable and fine particulate matter measurements (final report). Prep. for Environmental Protection Agency by Environmental Research and Technology, Inc. Concord, MA. Report No. EPA-450/4-81-035.

Weant, G.E., III, et al. 1978. Particulate control for fugitive dust. Research Triangle Institute, Research Triangle Park, NC. Report no. EPA/600/7-78/071.

Winchester, J.W. 1980. Sulfate formation in urban plumes. Prep. for Environmental Protection Agency by Florida State University, Department of Oceanography. Report No. EPA-600/J-80-356. 14 pp.

Winer, A.M. 1981. Investigation of the role of natural hydrocarbons in photochemical smog formation in California. (Final report June 19, 1979 - September 8, 1980.) University of California, Riverside, Statewide Air Pollution Research Center. 127 pp.

Wolcott, M. 1980. Summary report of several ambient carbon monoxide studies. Technical report. U.S. Environmental Protection Agency, Test and Evaluation Branch. Ann Arbor, MI. Report No. EPA-AA-TEB-81-9. 24 pp.

Wolcott, M. 1981. Carbon monoxide episodes. U.S. Environmental Protection Agency, Test and Evaluation Branch, Ann Arbor, MI. Report no. EPA-AA-TEB-EF-82-3. 13 pp.

10. APPENDIX

10.1 SUMMARY OF RESEARCH RECOMMENDATIONS MADE BY INDIVIDUALS INTERVIEWED IN ALBERTA

The following sections summarize, in point form, and not necessarily in order of priority, the unedited specific recommendations made by individuals interviewed in Alberta. These are presented within each of four major study categories: physical/chemical processes; monitoring; modelling; and effects/consequences. This segregation is somewhat artificial and is used for convenience only. The importance of the need for a unified interdisciplinary approach to the successful understanding of urban air pollution in Alberta cannot be overemphasized.

1. Physical/Chemical Processes

- Establish the contributions of sulphates, H_2S, and other contituents to the urban environment from outside sources. Use existing modelling techniques. (S-T REC. No. 7)*
- Correlate historical air quality data with meteorological conditions. Examine these on a year-to-year basis to explain and understand trends. (S-T REC. No. 1)*
- Correlate airborne aerosol concentrations with nephylometer measurements. (S-T REC. No. 6)*
- Update emission inventories and identify unique sources of exotic pollutants. Compare with other cities. (S-T REC. No. 5)*
- Examine the effects of pollutants on inadvertent weather modifications. (S-T REC. No. 6)*

---

*Indicates short-term (S-T), long-term (L-T) or public concern (PC) recommendations as classified in Section 7 of this report.

- Each industrial facility should provide Alberta Environment annually with a complete inventory of atmospheric emissions (volumes and chemical composition) from all sources (stacks, vents, and fugitive emissions). Furthermore, Alberta Environment is to undertake studies of specific types of industry to calibrate data sumbitted by industry. (S-T REC. No. 5)*
- Commission studies to better understand the chinook phenomena in Calgary and its direct impact on high pollution episodes. (S-T REC. No. 7)*
- Define the role of ice fog as a mechanism for removal of atmospheric pollutants (gaseous and particulate). (S-T REC. No. 6)*
- Examine the volatility of toxic waste sites. (S-T REC. No. 6)*
- Examine the sources and sinks of herbicides and pesticides, and their chemical transformation and deposition rates. (S-T REC. No. 6)*
- Develop an emission characterization for each industry category in accordance with EPA's list of priority pollutants. (not adopted)
- Examine the meteorological conditions that give rise to high pollution episodes to provide a better understanding of these phenomena in Alberta. (S-T REC. 7)*
- Define the composition of emissions from wood burning, particularly from air controlled, stoves (incomplete combustion). (S-T REC. No. 6)*
- Examine the effect of confinement due to tall buildings on concentrations at street levels. (S-T REC. No. 4)*

---

*Indicates short-term (S-T), long-term (L-T) or public concern (PC) recommendations as classified in Section 7 of this report.

2. Air Quality/Meteorological Monitoring

- Establish the downwind extent of urban plumes using continuous and episodic monitoring. (S-T REC. No. 7)*
- Intermittently monitor sulphates, heavy metals (arsenic, vanadium, lead), aldehydes, hydrogen peroxide, ammonia, nitrous oxides, and hydroxyl ion. This latter element may play a role in chemical transformations. (S-T REC. No. 3)*
- Establish a more comprehensive data base for the statistics of atmospheric stability as a function of wind speed and direction. Minisonde balloons are ideally suited for this. (S-T REC. No. 7)*
- Air quality data monitored and reported by the Strathcona Industrial Group should be made public and integrated with Alberta Environment's monitoring reports. (not adopted)
- Relocate the air quality monitoring station operated by Alberta Environment in the residential area of Calgary to another location where downwind concentrations within the urban plume can be measured. A distance of the order of 50 km should be considered. (S-T REC. No. 7)*
- Criteria for assessing urban air pollution should include constituents other than just the classical pollutants monitored by Alberta Environment. (S-T REC. No. 3)*
- Meteorological monitoring should be designed to provide an understanding of topographic effects within the urban centre (microscale), and circulation of pollutants out from and back into the urban space (mesoscale). (S-T REC. No. 7)*
- Alberta Environment should report separately on the concentrations of NO, NO_2 and NO_x. (S-T REC. No. 2)*
- Declare the current air quality monitoring station at Fort Saskatchewan as an official continuous station. (not adopted)

---

*Indicates short-term (S-T), long-term (L-T) or public concern (PC) recommendations as classified in Section 7 of this report.

- Total hydrocarbon measurements should be divided into the various reactive types. (S-T REC. No. 3)*
- Re-examine the reasons for the elimination of H_2S and SO_2 monitors from the two stations in the city of Calgary. (not adopted)
- Provide particulate characterization (chemical composition by size fraction). (S-T REC. No. 3)*
- Episodically, monitor nitric acid precipitation and nitrates in Edmonton. (S-T REC. No. 6)*
- Establish a network of surface wind monitoring stations along an east-west transect west of Calgary to look at up- and down-slope wind patterns. (S-T REC. No. 7)*
- Episodically monitor unsaturated hydrocarbons. (S-T REC. No. 3)*
- Examine the need to monitor indoor air quality. (PC REC. No. 7.3.3)*
- Use mass spectrometry to monitor chemical composition downwind of specific plants that contribute to urban air pollution. (S-T REC. Nos. 3 and 6)*
- Examine why lead is no longer reported by the NAPS network in Alberta. (S-T REC. No. 3)*
- Alberta Environment should officially inform (annually) city council and health officers (Edmonton and Calgary) on the status of urban air pollution. (PC REC. No. 7.3.2)*
- Establish an atmospheric science research station at Research Park in Calgary where interdisciplinary research on urban air pollution can be conducted. (not adopted)
- Correlate (short-term) air quality measurements recorded at the monitoring stations in the downtown area with measurements at street level. (S-T REC. No. 4)*

---

*Indicates short-term (S-T), long-term (L-T) or public concern (PC) recommendations as classified in Section 7 of this report.

- Alberta Environment should examine the field methodology for measuring COH at the official monitoring stations. (Specific reference was made to the compliance of the intake system to manufacturer's specifications.) (not adopted)
- Examine the adequacy of existing guidelines and enforcement measures within the urban air pollution context. (PC REC. No. 7.3.1)*
- Alberta Environment should seek public input in the event that guidelines are modified. (not adopted)
- Enforce provincial testing of vehicular emissions. (not adopted)
- Provide the public with air quality information on a comparative basis with other major centres in Canada. (PC REC. No. 2)*

3. Modelling

- Build on existing technology and adapt a model for application to prevailing urban conditions, for use as a research tool for understanding urban air pollution, and as a management tool for decision making. (L-T REC. No. 1)*
- Adapt a model or models for the development of response plans to accidental pipe ruptures and/or spills that may impinge on heavily populated urban areas. Consider transportation corridors (rail and truck) and pipelines. (L-T REC. No. 1)*
- All models must be validated within the urban Alberta setting. Criteria for validation and verification must be established by an interdisciplinary team of specialists. (L-T REC. No. 1)*

---

*Indicates short-term (S-T), long-term (L-T) or public concern (PC) recommendations as classified in Section 7 of this report.

4. Effects and Consequences

- Examine the effects on materials other than direct effects on cars of suspendable road salts during winter. (not adopted)
- Establish the effects of urban air pollution on green belts and city parks. (S-T REC. No. 6)*
- Define all constituents present in the atmosphere before potential effects can be explored. (not adopted)
- Define the pollution levels associated with real effects on human health. Alberta should consider adopting the Federal three-tier system (desirable, acceptable, and tolerable objectives). (not adopted)
- In the event of an accidental pipe rupture and/or toxic spill affecting humans, Alberta should undertake an in-depth epidemeological study to establish both short- and long-term effects on the affected population. (L-T REC. No. 2)*
- Review synergistic health effects as may be applicable to air pollutants in the Alberta urban environment. (not adopted)
- Recommend closure of the Edmonton Industrial airport. (Pollution and noise are discouraging residential development along flight paths.) (not adopted)

---

*Indicates short-term (S-T), long-term (L-T) or public concern (PC) recommendations as classified in Section 7 of this report.

10.2 LIST OF ACRONYMS AND SYMBOLS

AFB	Airforce base
CBD	Calgary business district
CDMU	Calgary Downtown Monitoring Unit
CFC	Chloro flurocarbons
CH_4	methane
CO	Carbon monoxide
COH	Coefficient of haze
COH_6	Carboxyhemoglobin
COSPEC	Correlation spectrometer
EHD	Environmental Health Directorate, Health and Welfare Canada
EPA	U.S. Environmental Protection Agency
EPS	Environmental Protection Service, Environment Canada
ESL	ESL Environmental Sciences Limited
H_2S	Hydrogen sulphide
H_2SO_4	Sulphuric acid
HC	Hydrocarbon
HNO_2	Nitrous acid
HNO_3	Nitric acid
HO_2	Hydroxide
IQUA	Index of Quality of Air
KI	Potassium iodide
LAX	Los Angeles airport
$\mu g/m^3$	Micrograms per cubic metre
mb	Millibar
MSS	Multispectral scanner
NAAQO	National Ambient Air Quality Objectives
NAPS	National Air Pollution Surveillance
NATO	North Atlantic Treaty Organization
NH_4HSO_4	Ammonium bisulphate
$(NH_4)_2SO4$	Ammonium sulphate

NMHC	Non-methane hydrocarbons
NO	Nitrogen oxide
NO_2	Nitrogen dioxide
NO_x	Nitrogen oxides
NRCC	National Research Council, Canada
O_3	Ozone
OH	Hydroxyl radical
ppb	Parts per billion
pphm	Parts per hundred million
ppm	Parts per million
pH	A measure of the acidity (or alkalinity) of solutions
PAH	Polycyclic aromatic hydrocarbons
PAN	Peroxyacetyl nitrate
PCD	Pollution Control Division, Alberta Environment
RAPS	St. Louis Regional Air Pollution Study
RCHO	Aldehydes
RHC	Reactive hydrocarbons
RMD	Research Management Division, Alberta Environment
S	Sulphur
SO_2	Sulphur dioxide
SO_4	Sulphate
SODAR	Instrument for the continuous measurement of inversion heights
TSP	Total suspended particulates
TAGA	Trade name for an air quality analyser
THC	Total hydrocarbons
UNAMAP	User's Network of Atmospheric Models for Air Pollution
UCLA	University of California, Los Angeles
UV	Ultraviolet radiation
WHO	World Health Organization
WMO	World Meteorological Organization